Physics with the Panda Detector at GSI

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Proton Driver Workshop
Fermilab, 7 Oct 2004

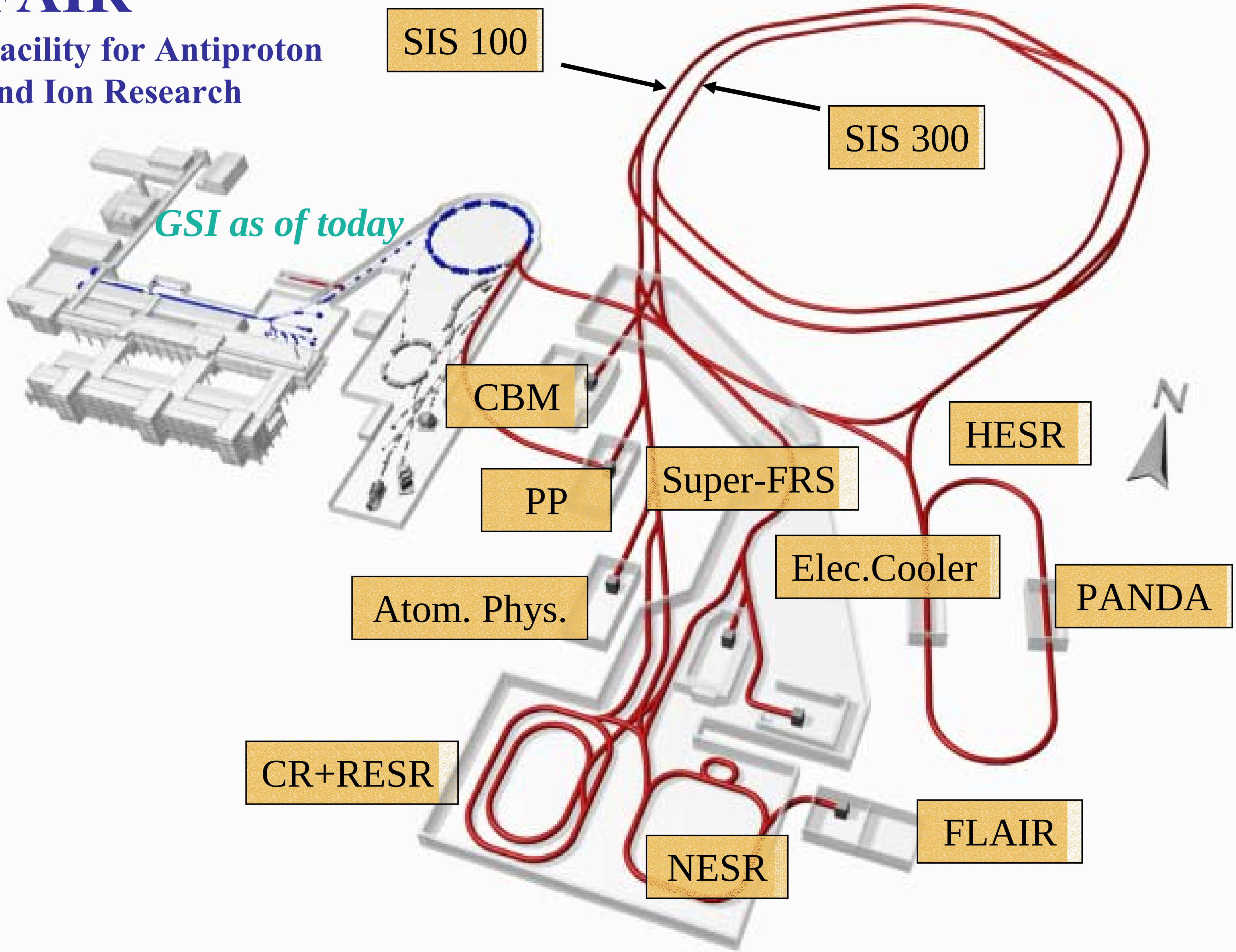
Outline

- Overview of the project
- Antiproton physics program
- The Panda detector concept
- Panda activities in Italy
- Conclusions

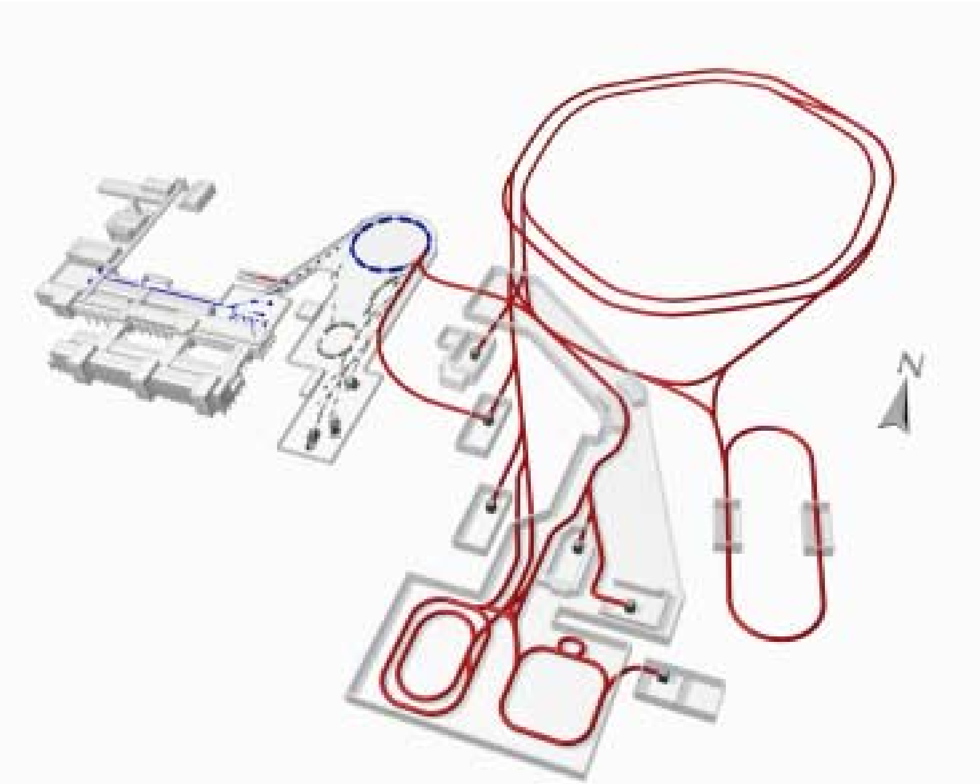
The GSI future project

FAIR

Facility for Antiproton and Ion Research



FAIR: Facility for Antiproton and Ion Research



Primary Beams

- 10^{12}/s; 1.5 GeV/u; $^{238}U^{28+}$
- Factor 100-1000 over present in intensity
- 2(4)x10^{13}/s 30 GeV protons
- 10^{10}/s $^{238}U^{73+}$ up to 25 (- 35) GeV/u

Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 GeV/u; up to factor 10 000 in intensity over present
- Antiprotons 3 - 30 GeV

Storage and Cooler Rings

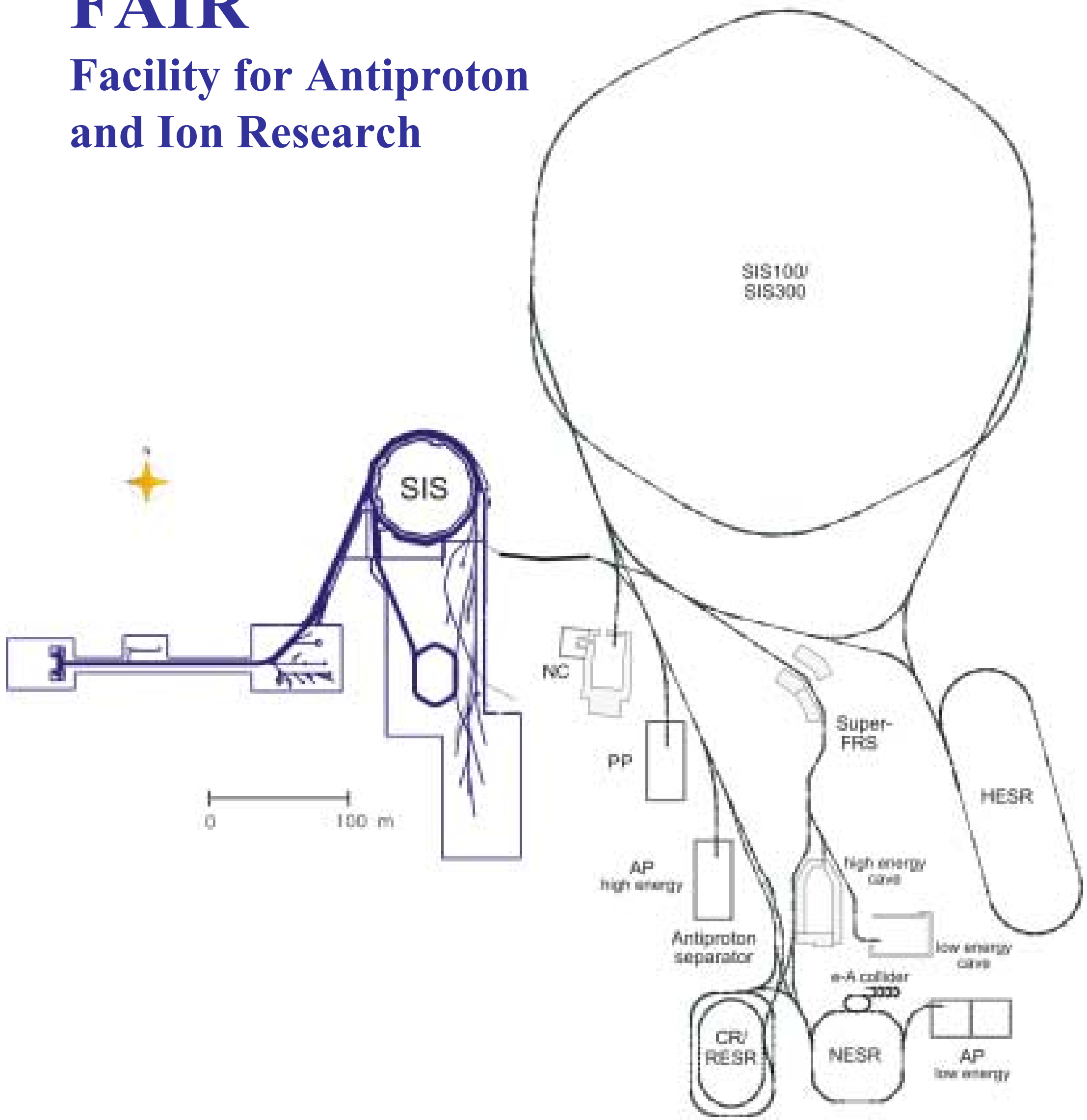
- Radioactive beams
- e – A collider
- 10^{11} stored and cooled 0.8 - 14.5 GeV antiprotons

Key Technical Features

- Cooled beams
- Rapidly cycling superconducting magnets

FAIR

Facility for Antiproton and Ion Research



research areas:

- Nuclear Structure Physics and Nuclear Astrophysics with Radioactive Ion-Beams
- Hadron Physics with $\bar{p}$ - Beams
- Physics of Nuclear Matter with Relativistic Nuclear Collisions
- Plasma Physics with highly bunched Laser- and Ion-Beams
- Atomic Physics and Applied Science
- Accelerator Physics

Antiproton Physics Program

- Charmonium Spectroscopy. Precision measurement of masses, widths and branching ratios of all $(c\bar{c})$ states (hydrogen atom of QCD).
- Search for gluonic excitations (hybrids, glueballs) in the charmonium mass range (3-5 GeV/c^2).
- Search for modifications of meson properties in the nuclear medium, and their possible relation to the partial restoration of chiral symmetry for light quarks.
- Precision γ-ray spectroscopy of single and double hypernuclei, to extract information on their structure and on the hyperon-nucleon and hyperon-hyperon interaction.

The GSI $\bar{p}$ Facility

HESR = High Energy Storage Ring

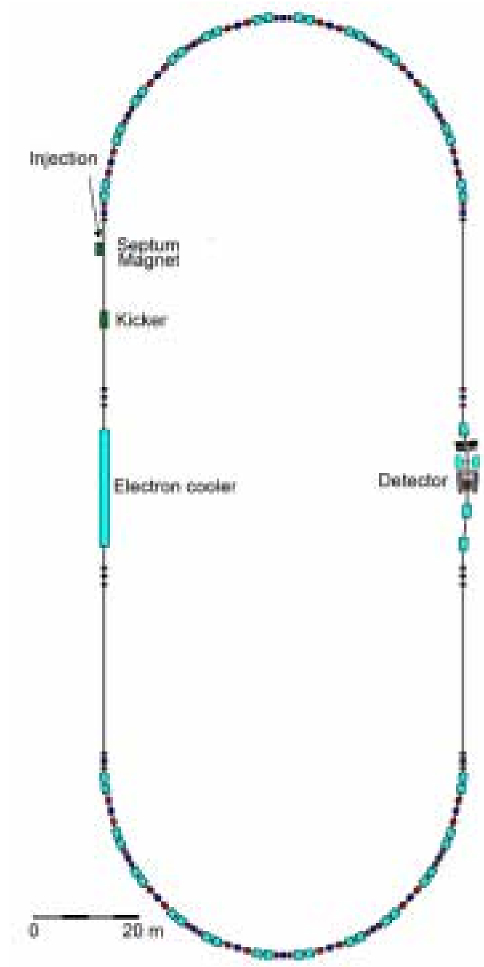
- Production rate 2×10^{7}/sec
- P_{beam} = 1 - 15 GeV/c
- N_{stored} = 5×10^{10} $\bar{p}$

High luminosity mode

- Luminosity = 2×10^{32} cm^{-2}s^{-1}
- dp/p~10^{-4} (stochastic cooling)

High resolution mode

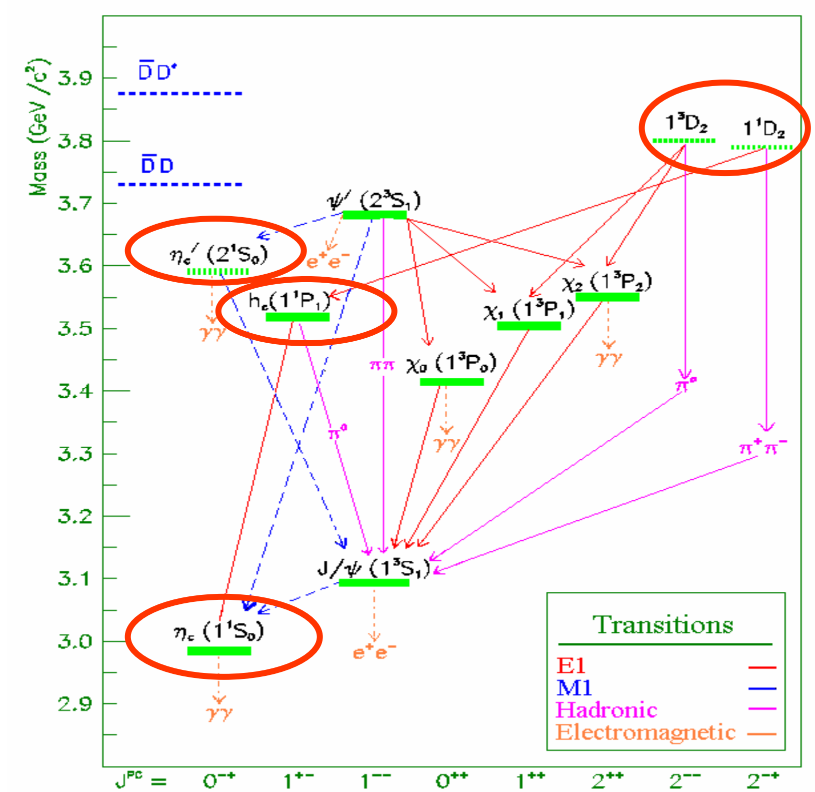
- dp/p~10^{-5} (el. cooling < 8 GeV/c)
- Luminosity = 10^{31} cm^{-2}s^{-1}



Charmonium Spectroscopy

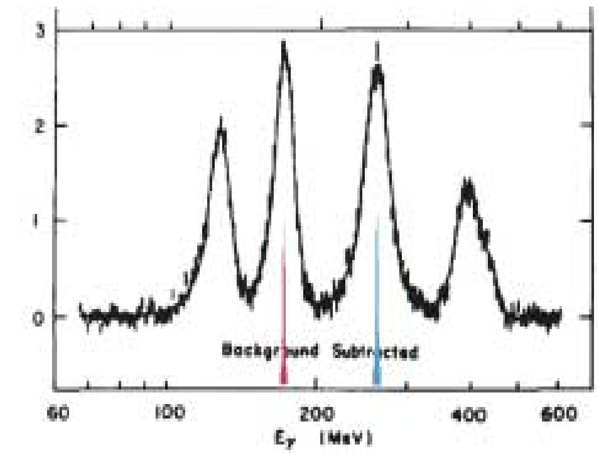
The charmonium system has often been called the positronium of QCD. Non relativistic potential models (with relativistic corrections) and PQCD make it possible to calculate masses, widths and branching ratios to be compared with experiment.

In $\bar{p}p$ annihilations states with all quantum numbers can be formed directly: the resonace parameters are determined from the beam parameters, and do not depend on energy and momentum resolution of the detector.



comparison e^+e^- versus $p\bar{p}$

Crystall Ball

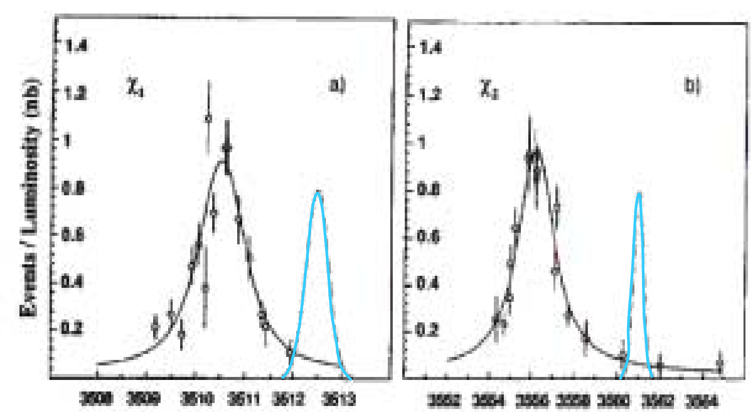


e^+e^- interactions:
only 1^{--} states formed
other states populated in secondary decays
(moderate mass resolution)

production of $\chi_{1,2}$

$e^+e^- \rightarrow \psi'$
$\quad\hookrightarrow \gamma\chi_{1,2}$
$\quad\quad\hookrightarrow \gamma\gamma\, J/\psi$
$\quad\quad\quad\hookrightarrow \gamma\gamma e^+e^-$

E 760 (Fermilab)



σ_m (beam) = 0.5 MeV

$p\bar{p}$ reactions:
all states directly formed
(very good mass resolution)

formation of $\chi_{1,2}$

$\bar{p}p \rightarrow \chi_{1,2}$
$\quad\hookrightarrow \gamma\, J/\psi$
$\quad\quad\hookrightarrow \gamma e^+e^-$

Charmonium Topics

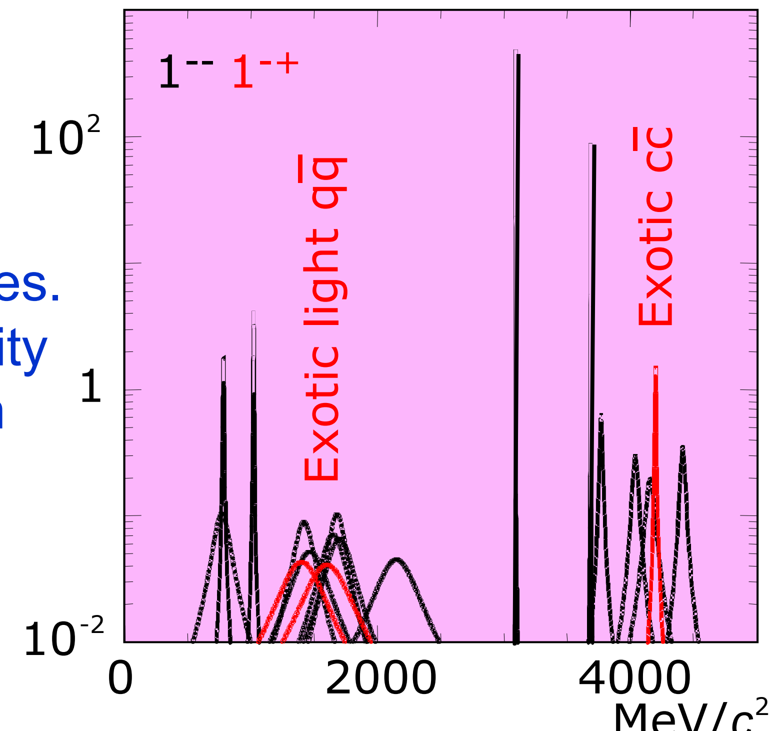
- All 8 states below threshold have been observed, but only 7 of them of them are supported by strong experimental evidence. The study of the h_c remains a very high priority in charmonium physics.
- The agreement between the various measurements of the η_c mass and width is not satisfactory. New, high-precision measurments are needed. The large value of the total width needs to be understood.
- The study of the η'_c has just started. Small splitting from the ψ' must be understood. Width and decay modes must be measured.
- The angular distributions in the radiative decay of the triplet P states must be measured with higher accuracy.
- The entire region above open charm threshold must be explored in great detail, in particular the missing D states must be found.
- Decay modes of all charmonium states must be studied in greater detail: new modes must be found, existing puzzles must be solved (e.g. ρ-π), radiative decays must be measured with higher precision.

Hybrids and Glueballs

The QCD spectrum is much richer than that of the quark model as the gluons can also act as hadron components.

Glueballs states of pure glue

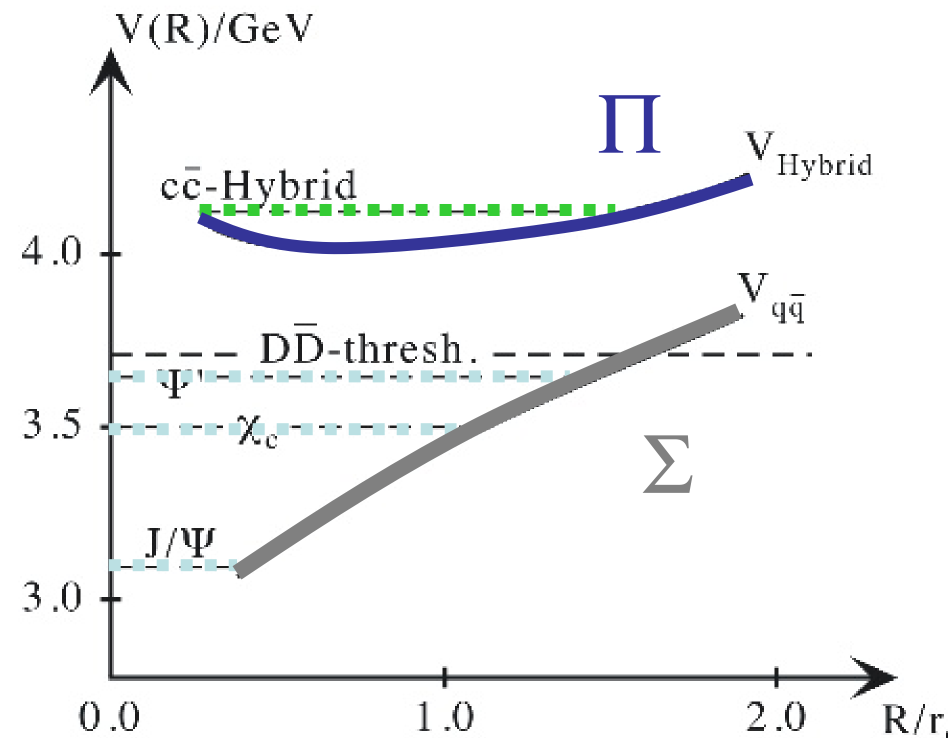
Hybrids $q\bar{q}g$



- In the light meson spectrum exotic states overlap with conventional states.
- In the $c\bar{c}$ meson spectrum the density of states is lower and the exotics can be resolved unambiguously

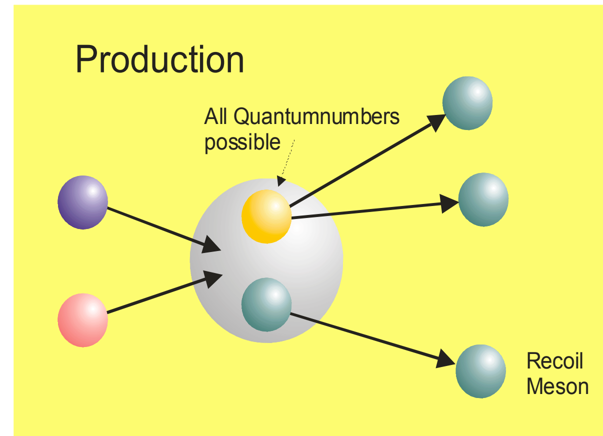
Charmonium Hybrids

- Fluxtube-Modell predicts DD** decays
  - if m_H<4,29 GeV
    $\rightarrow$ Γ_H<50 MeV
- Some exotics can decay neither to DD nor to DD*
  - e.g.: $J^{PC}(H)=0^{+-}$
    - fluxtube allowed
      $J/\psi f_2$, $J/\psi(\pi\pi)_S$,$h_{1c}\eta$
    - fluxtube forbidden
      $\chi_{c0}\omega$,$\chi_{c0}\phi$,$\chi_{c2}\omega$,$\chi_{c2}\phi$,$\eta_c h_1$
  - Small number of final states with small phasespace

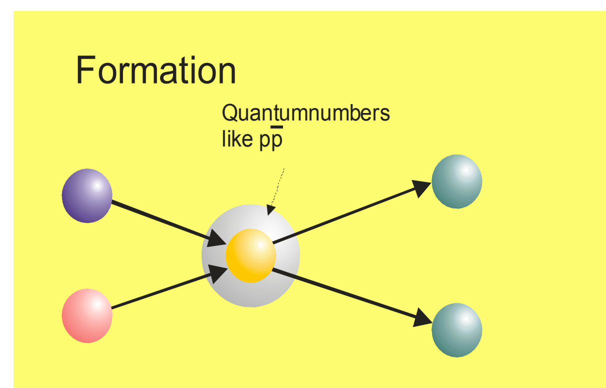


Charmonium Hybrids

- Gluon rich process creates gluonic excitation in a direct way
  - ccbar requires the quarks to annihilate (no rearrangement)
  - yield comparable to charmonium production



- 2 complementary techniques
  - Production (Fixed-Momentum)
  - Formation (Broad- and Fine-Scans)



- Momentum range for a survey
  - $p \rightarrow \sim 15$ GeV

Heavy Glueballs

Light gg/ggg systems are complicated to identify.

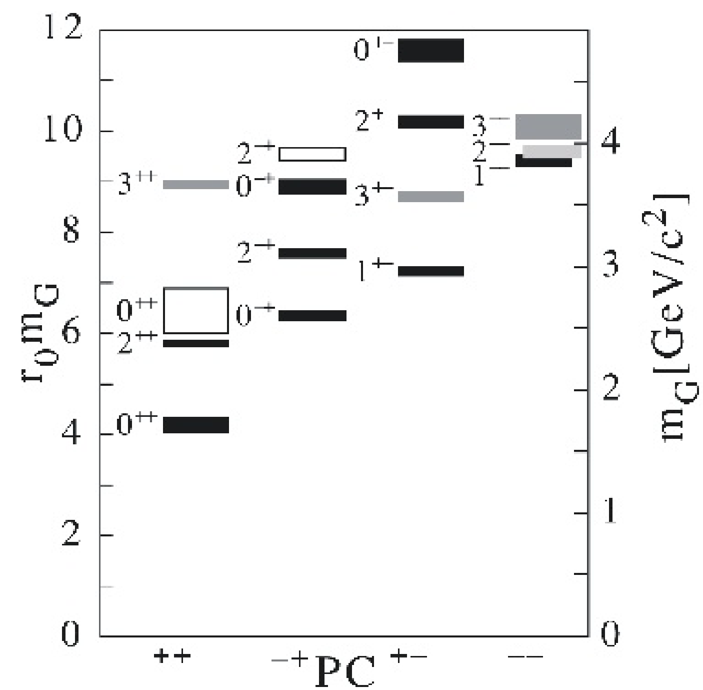
Exotic heavy glueballs:

- $m(0^{+-}) = 4140(50)(200)$ MeV
- $m(2^{+-}) = 4740(70)(230)$ MeV

Width unknown

Flavour blindness predicts decays into charmed final states.

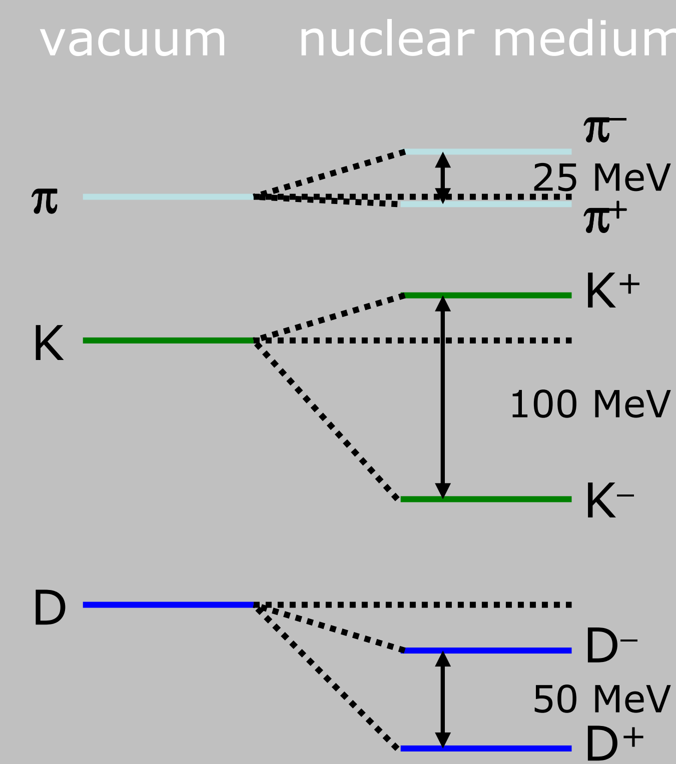
Same run period as hybrids.



Morningstar und Peardon, PRD60 (1999) 034509
Morningstar und Peardon, PRD56 (1997) 4043

Hadrons in Nuclear Matter

- Partial restoration of chiral symmetry in nuclear matter
  - Light quarks are sensitive to quark condensate
- Evidence for mass changes of pions and kaons has been deduced previously:
  - deeply bound pionic atoms
  - (anti)kaon yield and phase space distribution
- Ds are the QCD analog of the H-atom.
  - chiral symmetry to be studied on a single light quark

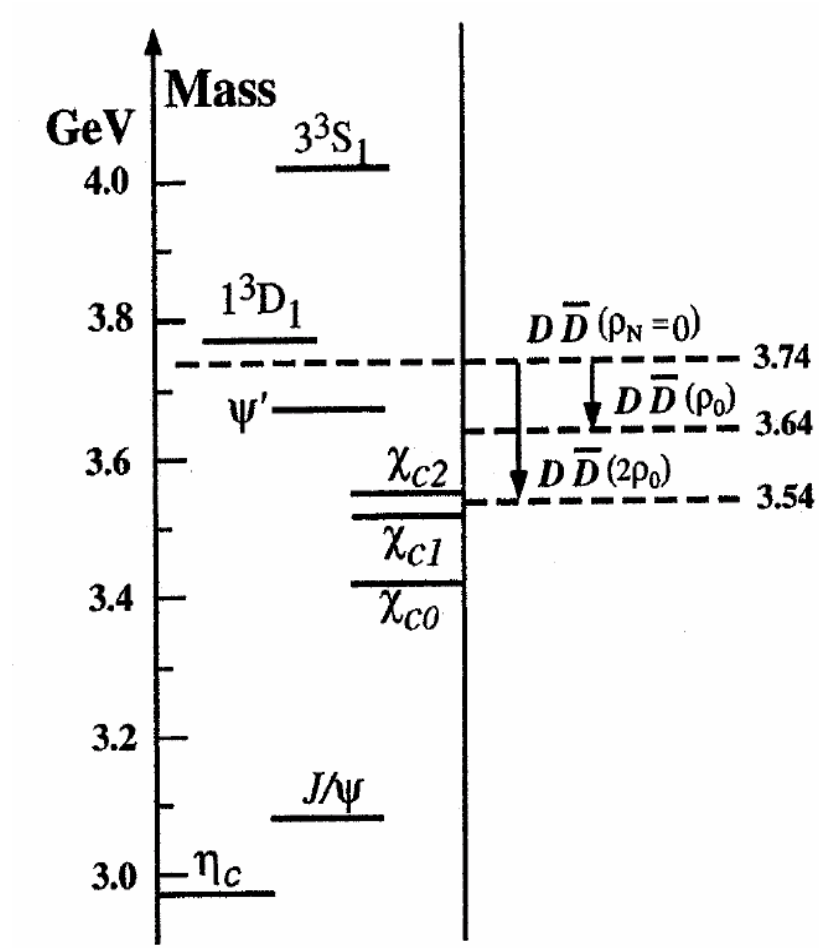


Hayaski, PLB 487 (2000) 96
Morath, Lee, Weise, priv. Comm.

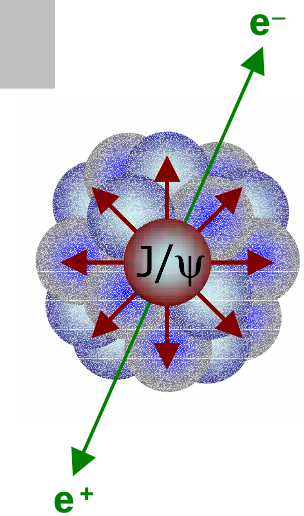
Charmonium in the Nuclei

- Lowering of the D^+D^- mass
  - allow charmonium states to decay into this channel,
  - thus resulting in a dramatic increase of width

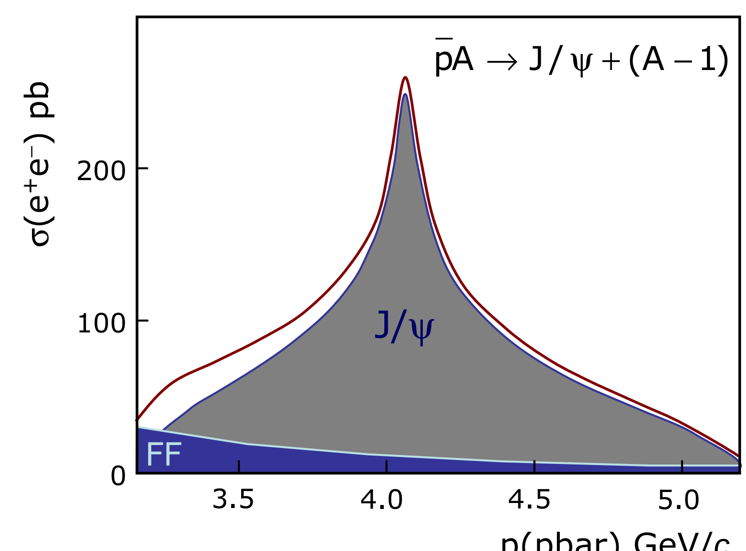
- Idea
  - Study relative changes of yield and width of the charmonium states.



J/ψ Absorption in Nuclei

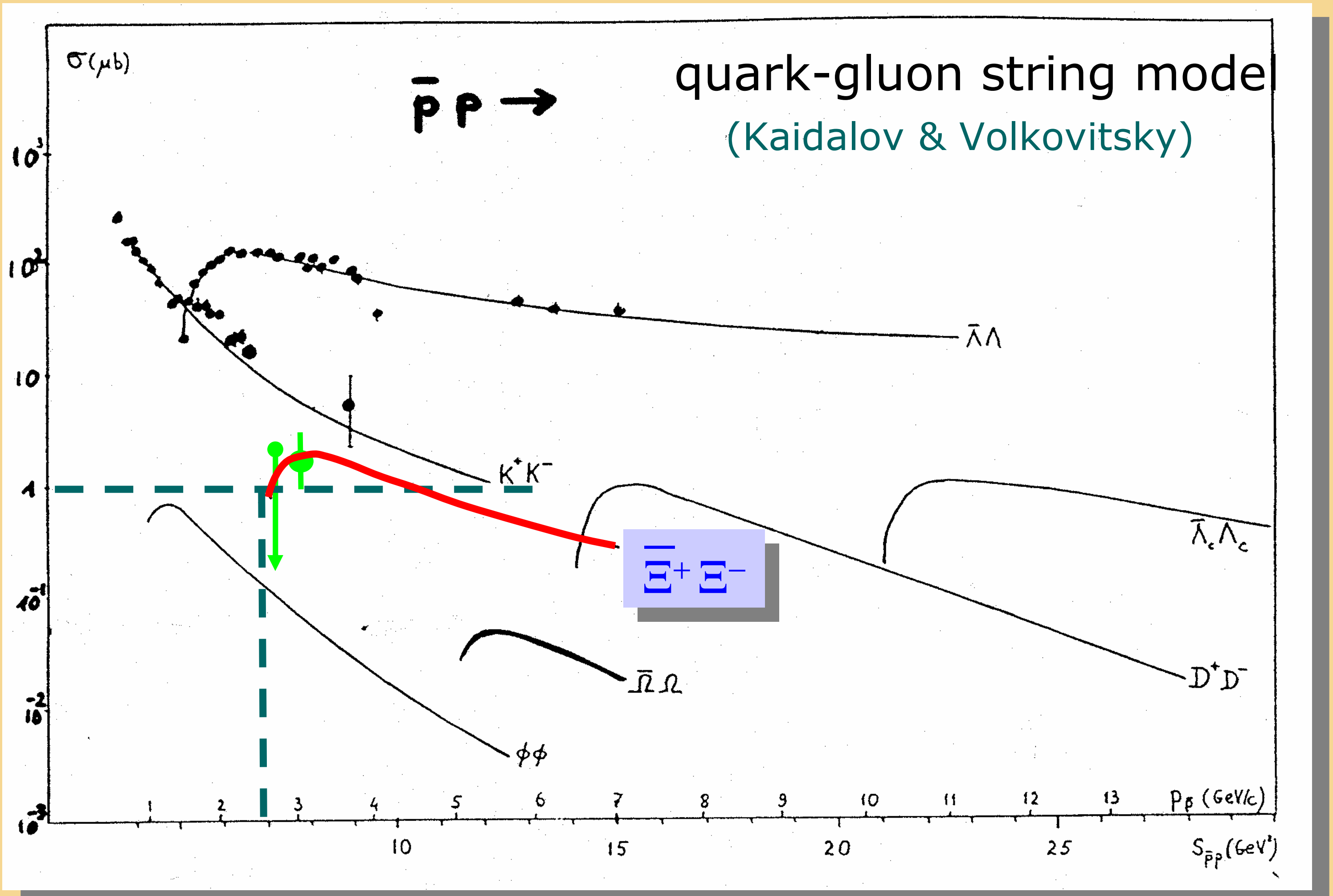


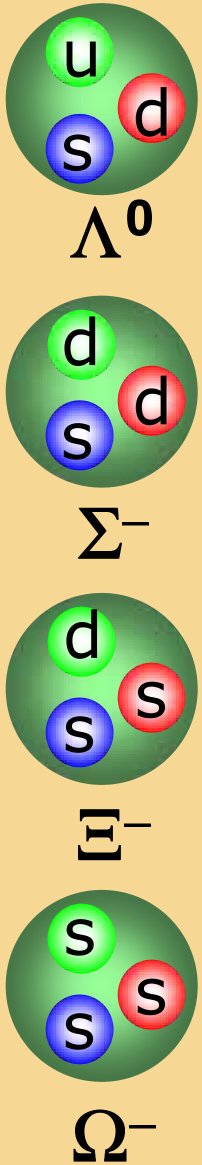
- Important for the understanding of heavy ion collisions
  - Related to QGP
- Reaction
  - $\bar{p} + A \rightarrow J/\Psi + (A\text{-}1)$
- A complete set of measurements could be done
  - J/ψ, ψ‘, χ_J on different nuclear targets
  - Longitudinal and transverse Fermi-distribution is measurable



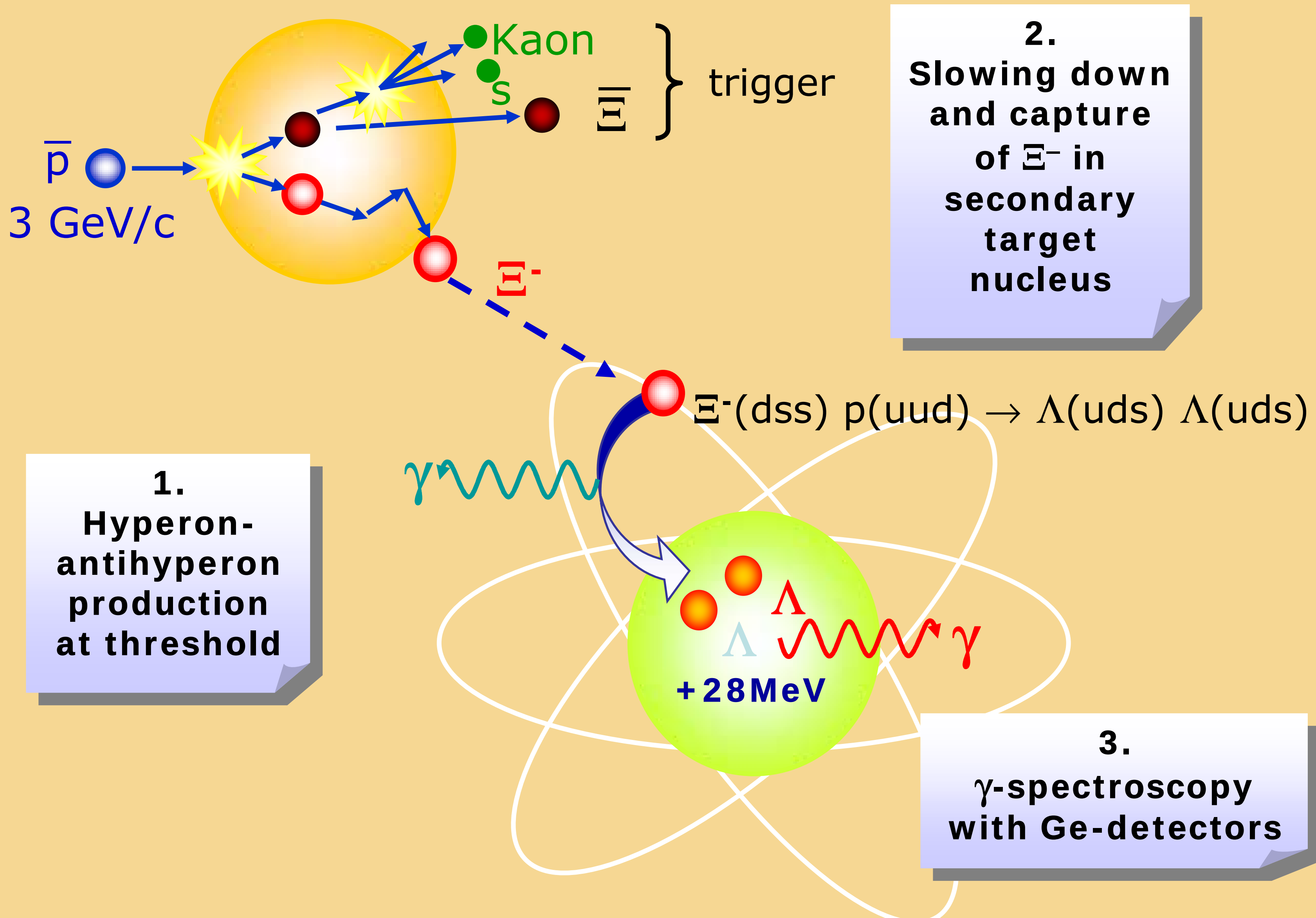
Hypernuclear Physics

- Use pp Interaction to produce a hyperon "beam" ($t \sim 10^{-10}$ s) which is tagged by the antihyperon or its decay products





Production of Double Hypernuclei



Expected Counting Rate

- Ingredients (golden events)
  - luminosity $2\cdot10^{32}$ cm^{-2}s^{-1}
  - $\Xi^+\Xi^-$ cross section 2mb for pp → 700 Hz
  - p (100-500 MeV/c) $p_{500} \approx 0.0005$
  - Ξ^+ reconstruction probability 0.5
  - stopping and capture probability $p_{CAP} \approx 0.20$
  - total captured Ξ^- → 3000 / day
  - Ξ^- to $\Lambda\Lambda$-nucleus conversion probability $p_{\Lambda\Lambda} \approx 0.05$
  - total $\Lambda\Lambda$ hypernucleus production → 4500 /month
  - gamma emission/event, $p_\gamma \approx 0.5$
  - γ-ray peak efficiency $p_{GE} \approx 0.1$

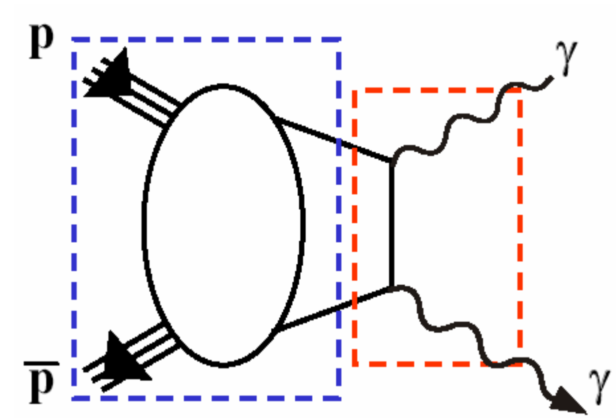
- ~7/day „golden" γ-ray events (Ξ^+ trigger)
- ~700/day with KK trigger

high resolution γ-spectroscopy of double hypernuclei will be feasible

Other Physics Topics

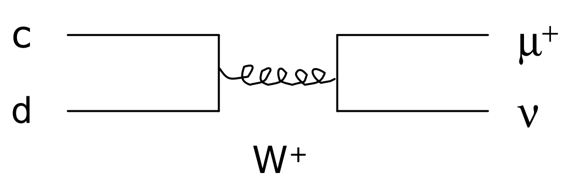
- Reversed Deeply Virtual Compton Scattering
- Drell-Yan Process – Transverse Quark Distributions (see app.)

- CP-violation (D/Λ – sector)
  - D^0D^0 mixing
    SM prediction $< 10^{-8}$
  - compare angular decay asymmetries for $\Lambda\bar{\Lambda}$
    SM prediction $\sim 2 \cdot 10^{-5}$

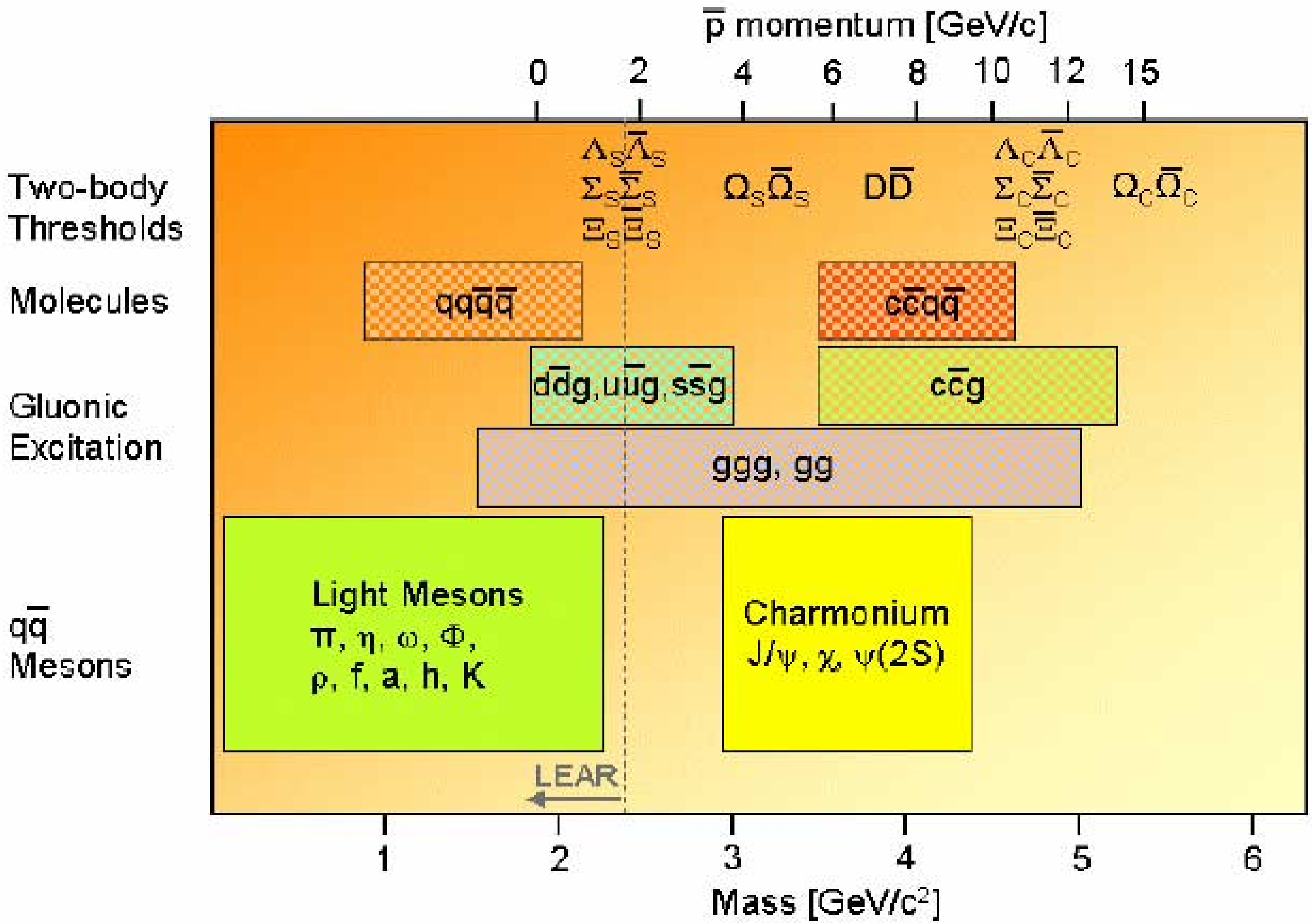


Cross section $\sigma \approx 2.5$pb @ s ≈ 10 GeV^2
L = $2 \cdot 10^{32}$ cm-2 s-1$\rightarrow 10^3$ events per month

- Rare D-decays:
  $D^+ \rightarrow \mu^+ \nu$ (BR 10^{-4})



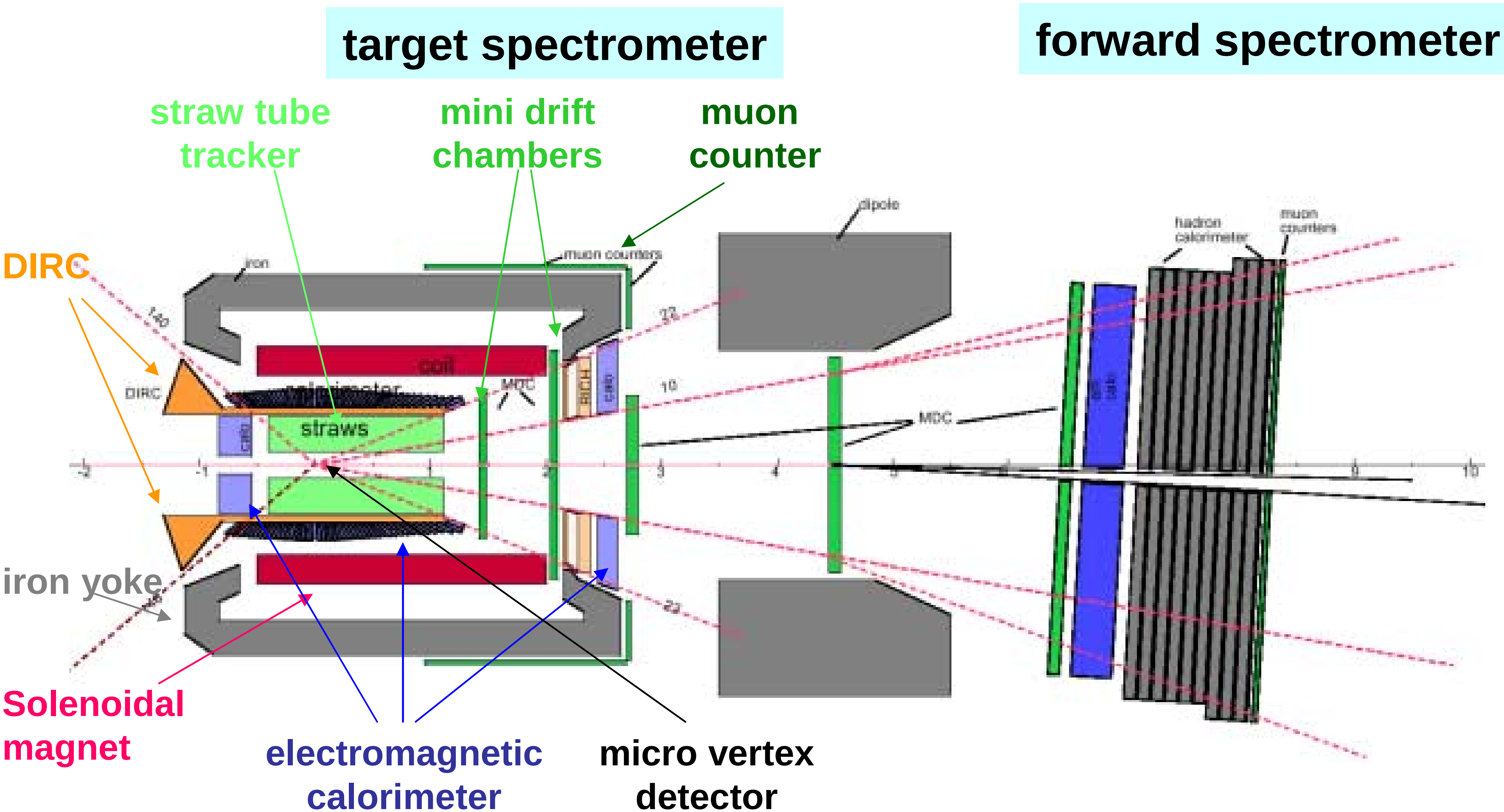
QCD Systems to be studied in Panda

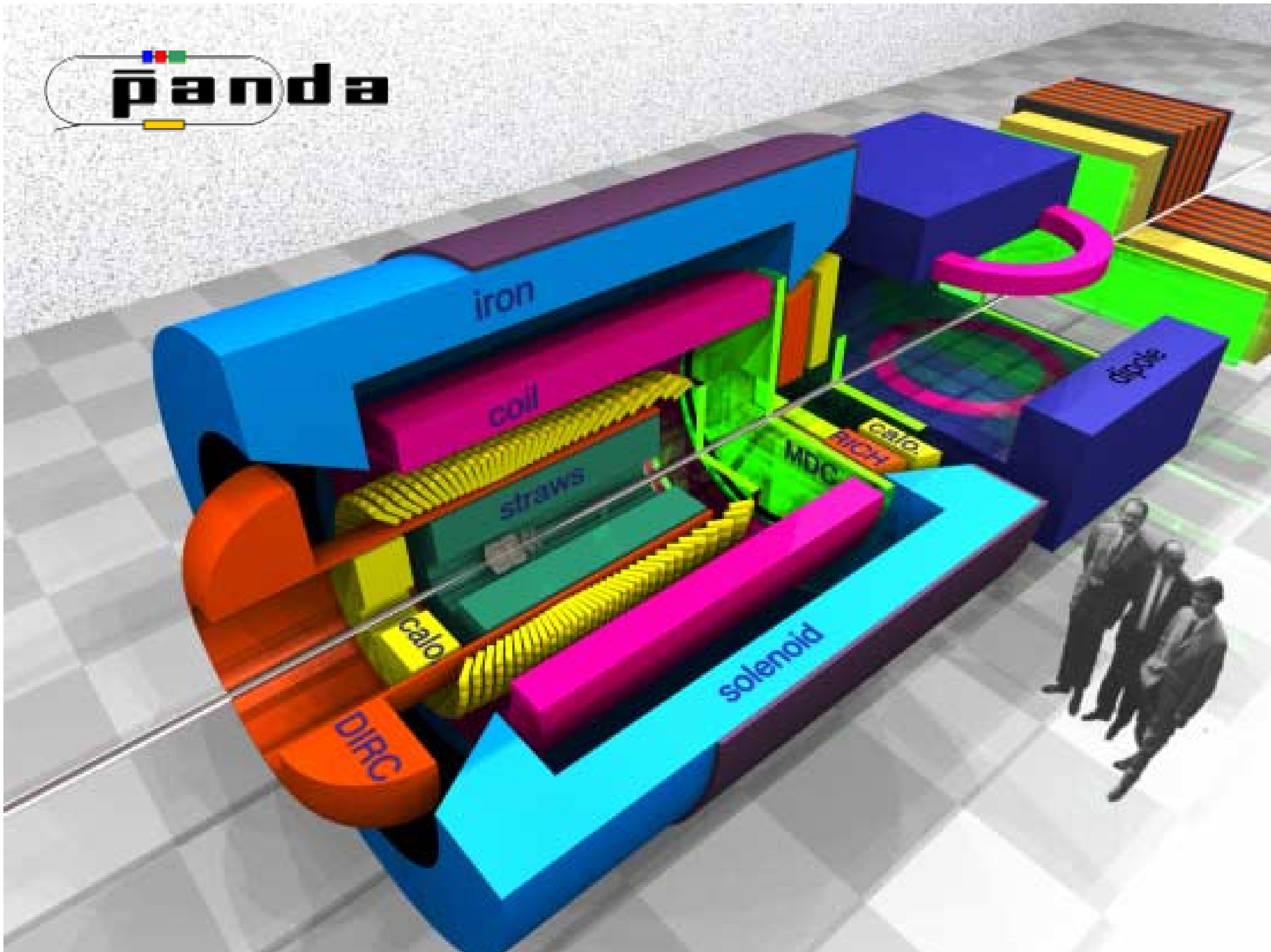


The detector

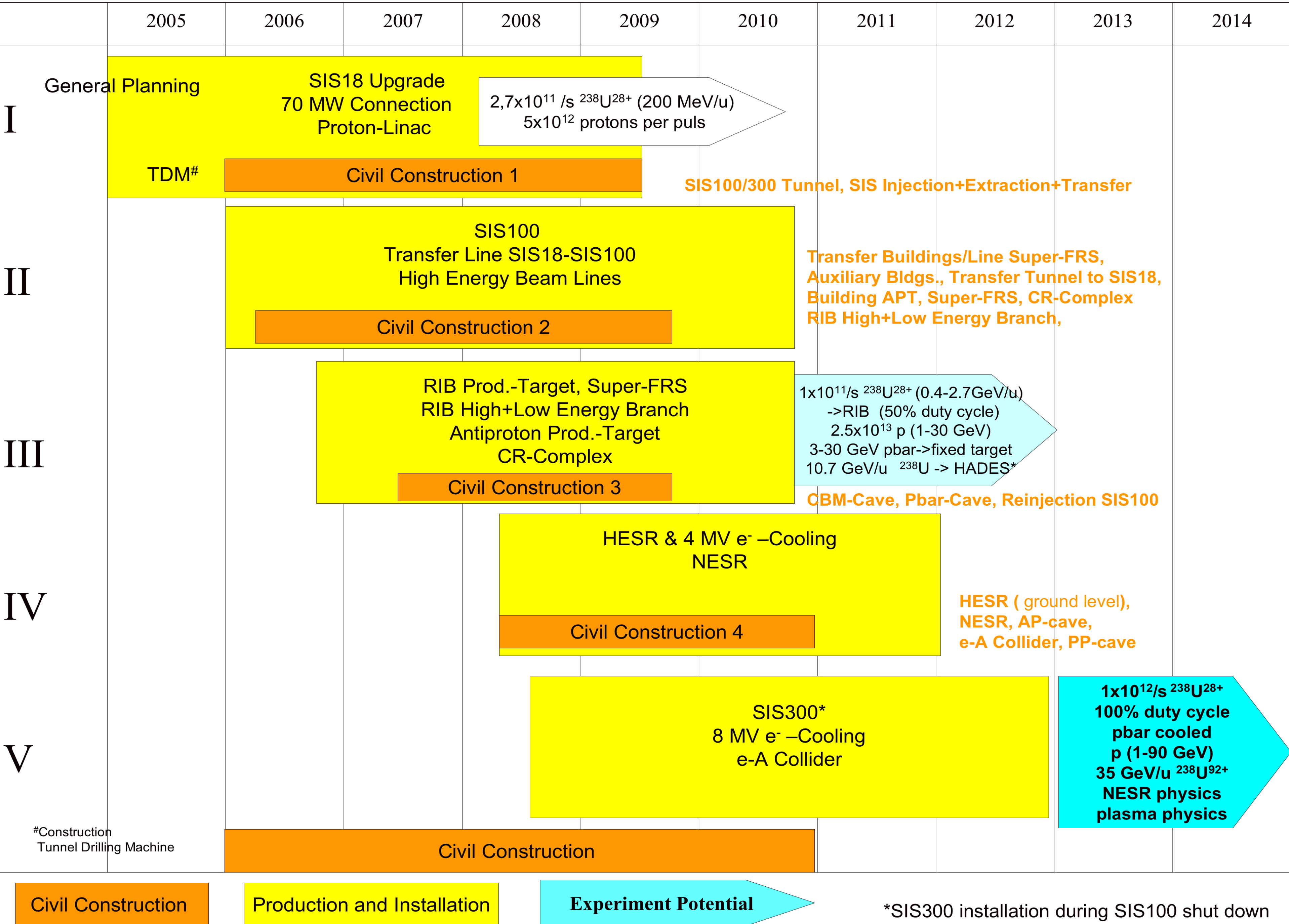
- Detector Requirements:
  - (Nearly) 4π solid angle coverage (partial wave analysis)
  - High-rate capability (2×10^{7} annihilations/s)
  - Good PID (γ, e, μ, π, K, p)
  - Momentum resolution ($\approx$ 1 %)
  - Vertex reconstruction for D, K^0_s, Λ
  - Efficient trigger
  - Modular design
- For Charmonium:
  - Pointlike interaction region
  - Lepton identification
  - Excellent calorimetry
    - Energy resolution
    - sensitivity to low-energy photons

Panda Detector Concept




panda
iron
coil
straws
calo
DIRC
solenoid
MDC
RICH
calo
dipole

Concept for staged Construction of the International Facility for Beams of Ions and Antiprotons



Cost - Schedules

•	Civil Construction	225 M€
	Accelerator Components	265 M€
	Detectors	185 M€ (Panda 31 M€)
	TOTAL	675 M€

- HESR and 4 MeV e-cooling: end 2009
- SIS200 and 8 MeV e-cooling: end 2011
- Panda data taking ~2011
- Activities in 2004
  - Letter of Intent due end 2003
  - Refine physics. Prepare physics book.
    - GSI physics workshop. GSI 13-17 Oct 2003
    - Frascati Workshop March 2004
  - Finalize detector design.
  - Prepare TDR.

PANDA Collaboration

- At present a group of **150 physicists**

from 40 institutions of 9 Countries.

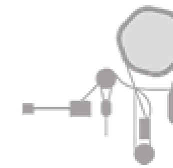
Austria - Germany – Italy – Netherlands – Poland – Russia – Sweden – U.K. – U.S.

Bochum, Bonn, Brescia, Catania, Cracow, Dresden, Dubna I + II, Edinburg, Erlangen, Ferrara, Frascati, Franhfurt, Genova, Giessen, Glasgow, KVI Groningen, GSI, FZ Jülich I + II, Los Alamos, Mainz, Milano, TU München, Münster, Northwestern, BINP Novosibirsk, Pavia, Silesia, Stockolm, Torino I + II, Torino Politecnico,Trieste, TSL Uppsala, Tübingen, Uppsala, SINS Warsaw, AAS Wien

Spokesperson: Ulrich Wiedner - Uppsala

http://www.gsi.de/hesr/panda

Conclusions



The HESR at the future GSI facility will deliver high-quality $\bar{p}$ beams with momenta up to 15 GeV/c ($\sqrt{s} \approx 5.5$ GeV).

This will allow Panda to carry out the following measurements:

- High resolution charmonium spectroscopy in formation experiments
- Study of gluonic excitations (glueballs, hybrids)
- Study of hadrons in nuclear matter
- Hypernuclear physics
- Deeply Virtual Compton Scattering and Drell-Yan

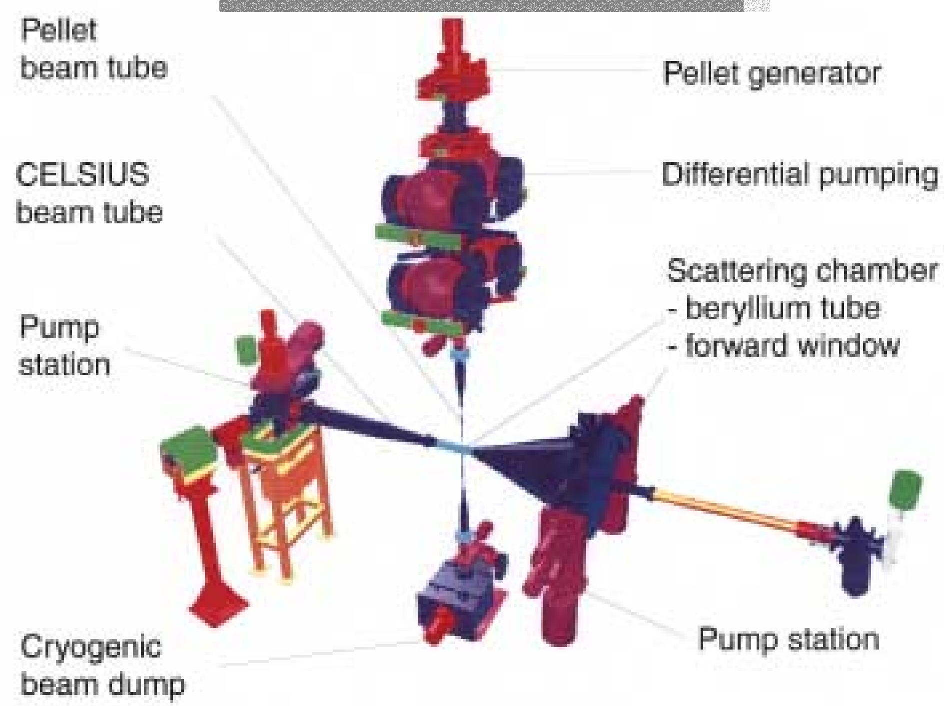
Panda Detector Components

Target

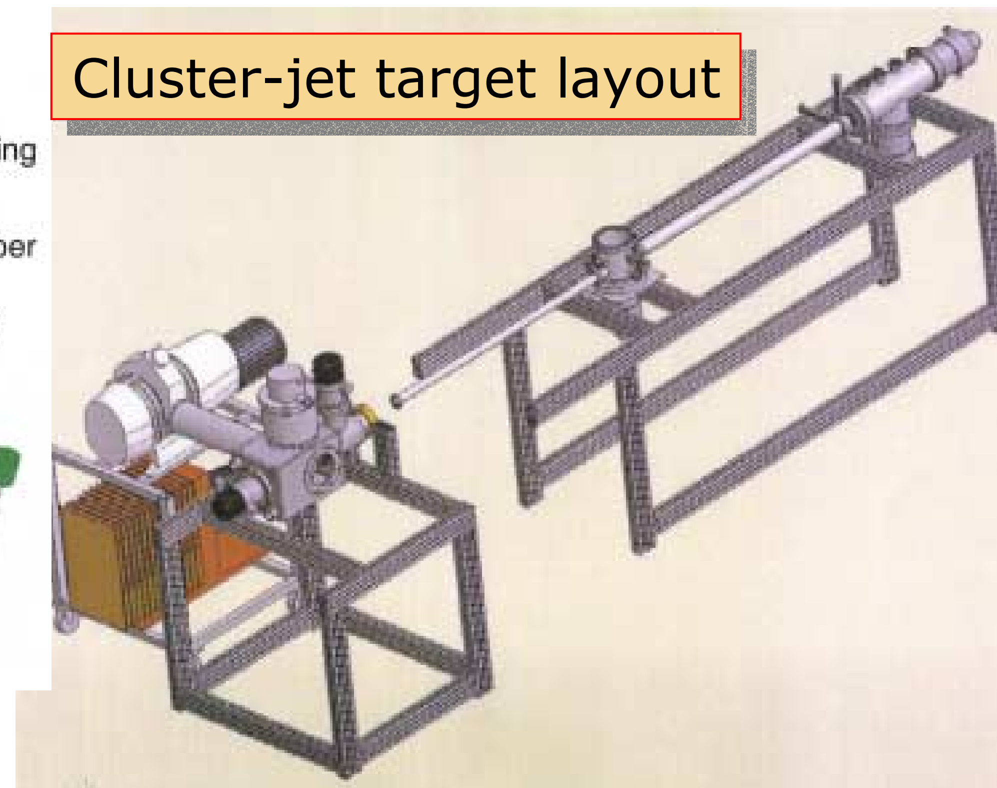
- A fiber/wire target will be needed for D physics,
- An internal cluster-jet/pellet target is under study:

  10^{16} atoms/cm^2 for D=20-40 μm

Pellet target layout

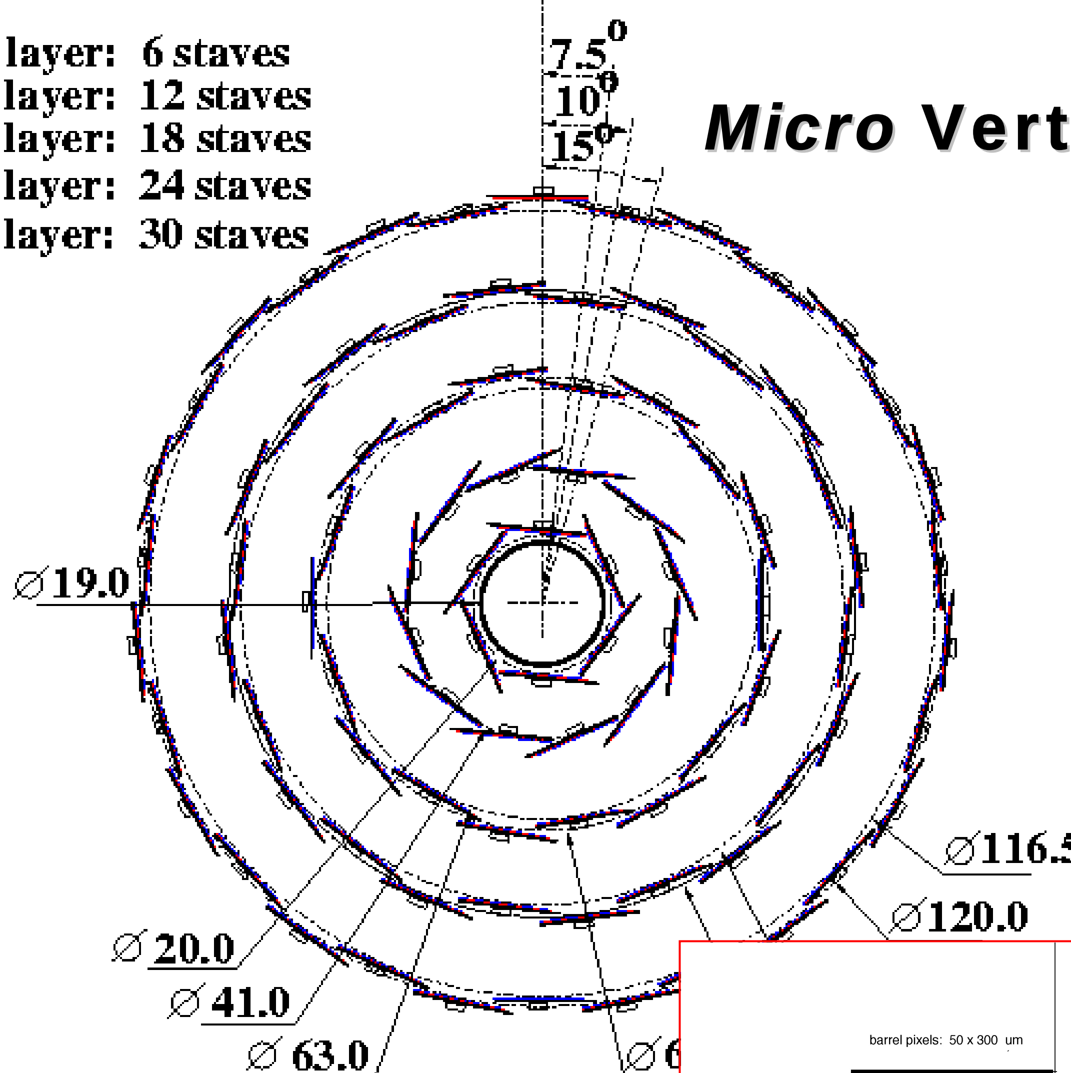


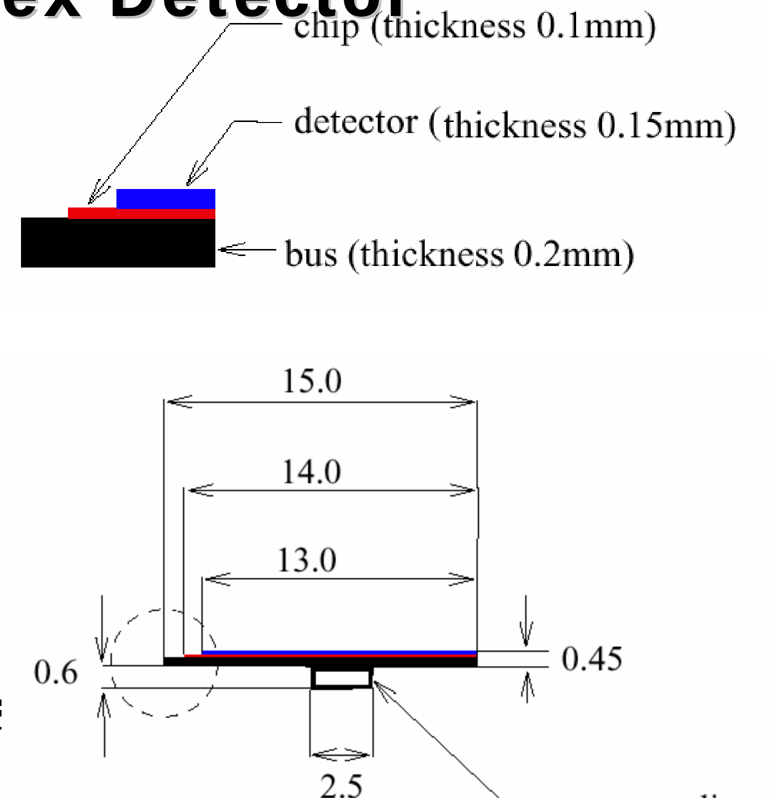
Cluster-jet target layout



Micro Vertex Detector

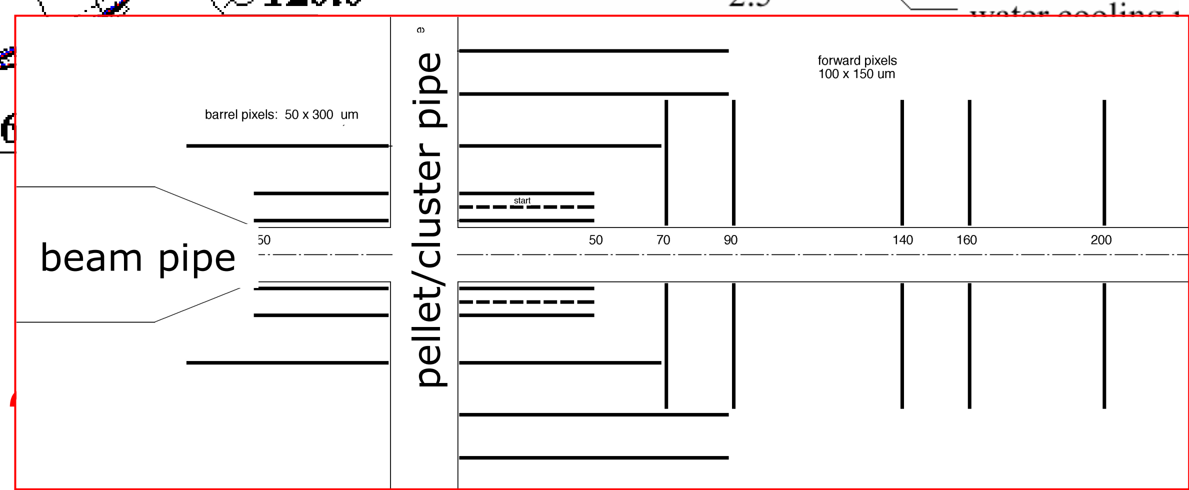
1 layer: 6 staves
2 layer: 12 staves
3 layer: 18 staves
4 layer: 24 staves
5 layer: 30 staves



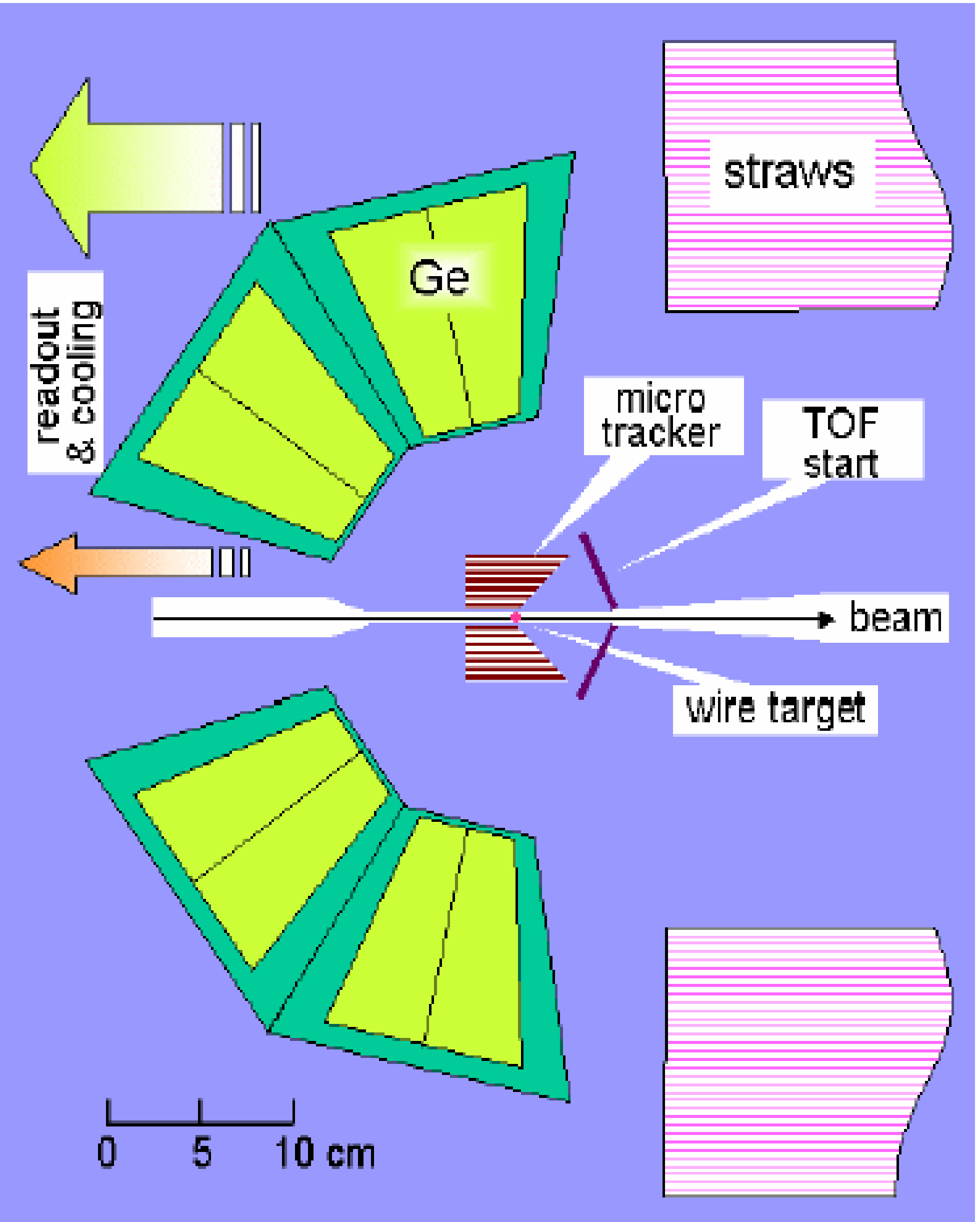


Conversion Prob:

primary e^+e^-



Hypernuclear Physics: Vertex Detector

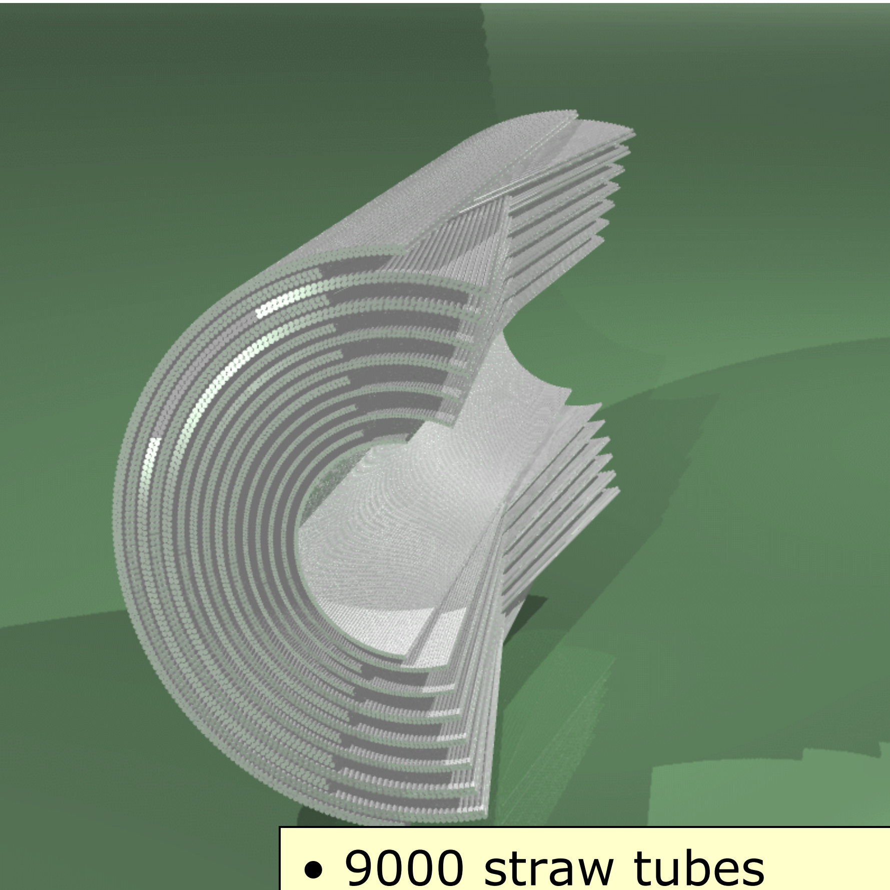


Development of a Super Segmented Clover Detector for the VEGA array

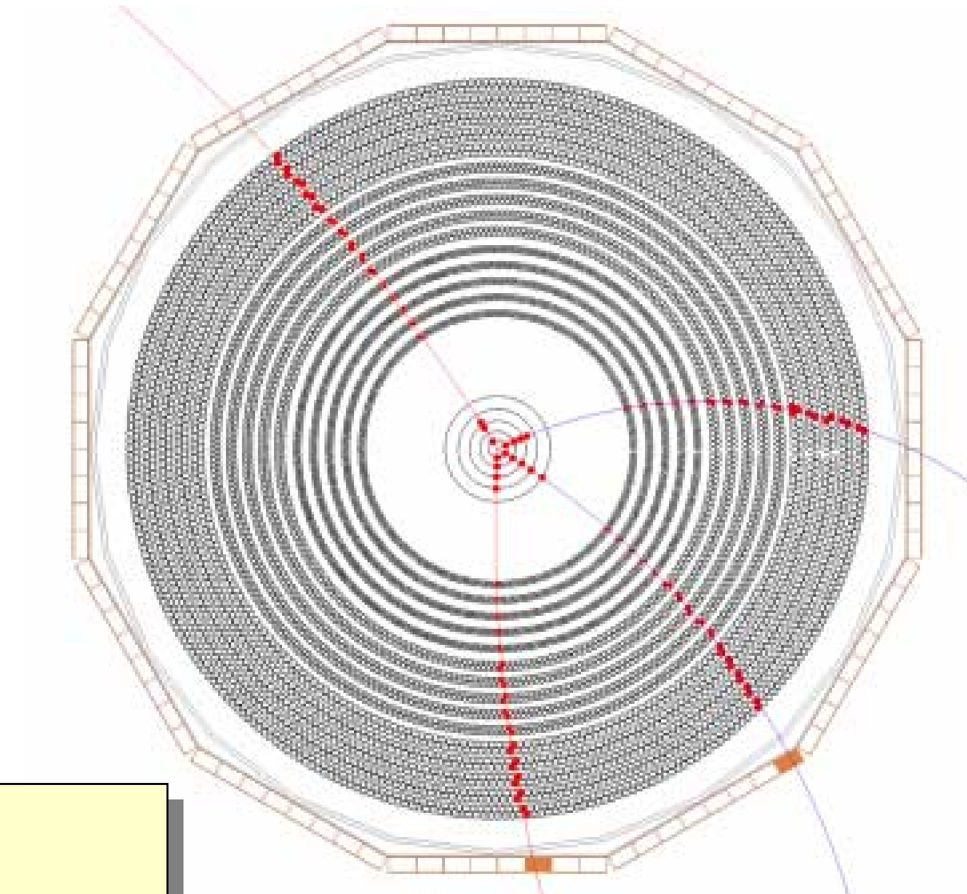
- High photopeak efficiency (ε_{ph} > 0.3)
- Good angular resolution to increase Doppler correction capability (up to v/c ~ 0.5)

- High rate capability
- Fast background rejection
- Operation into high magnetic fields

Central Tracking Detectors



- 9000 straw tubes
- 15 double layers
- 2-14 layers are
  with angle between 4-9°
- tube length –1.5 m
- tube diameters – 4, 6, 8 mm

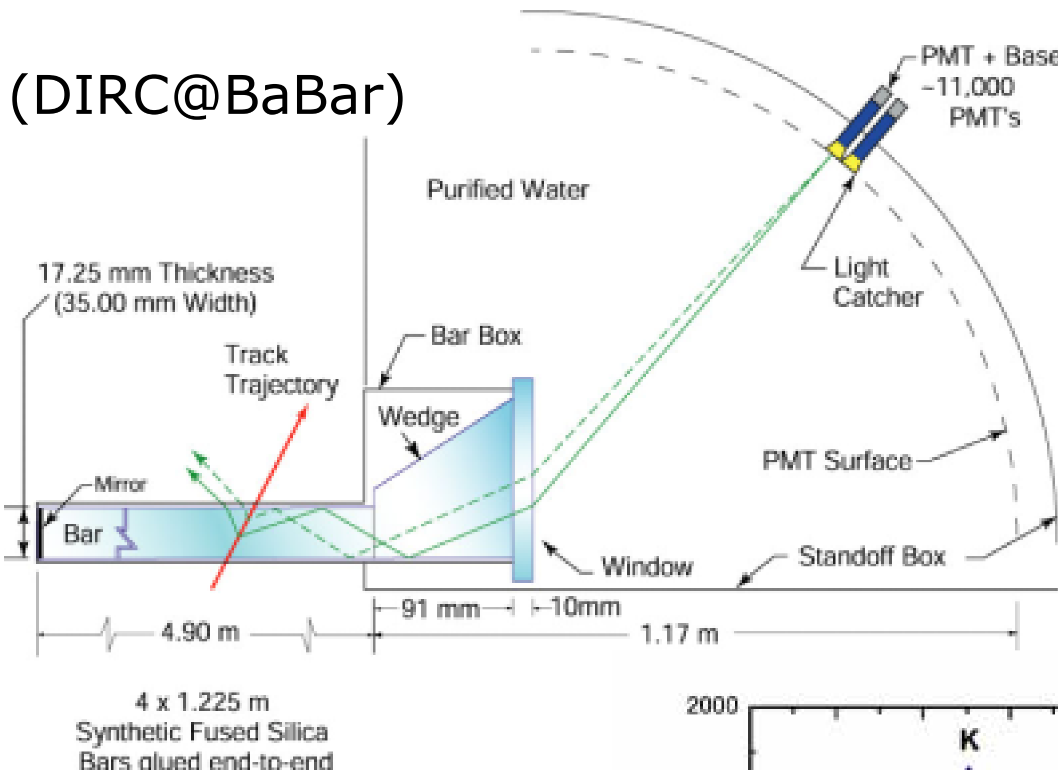


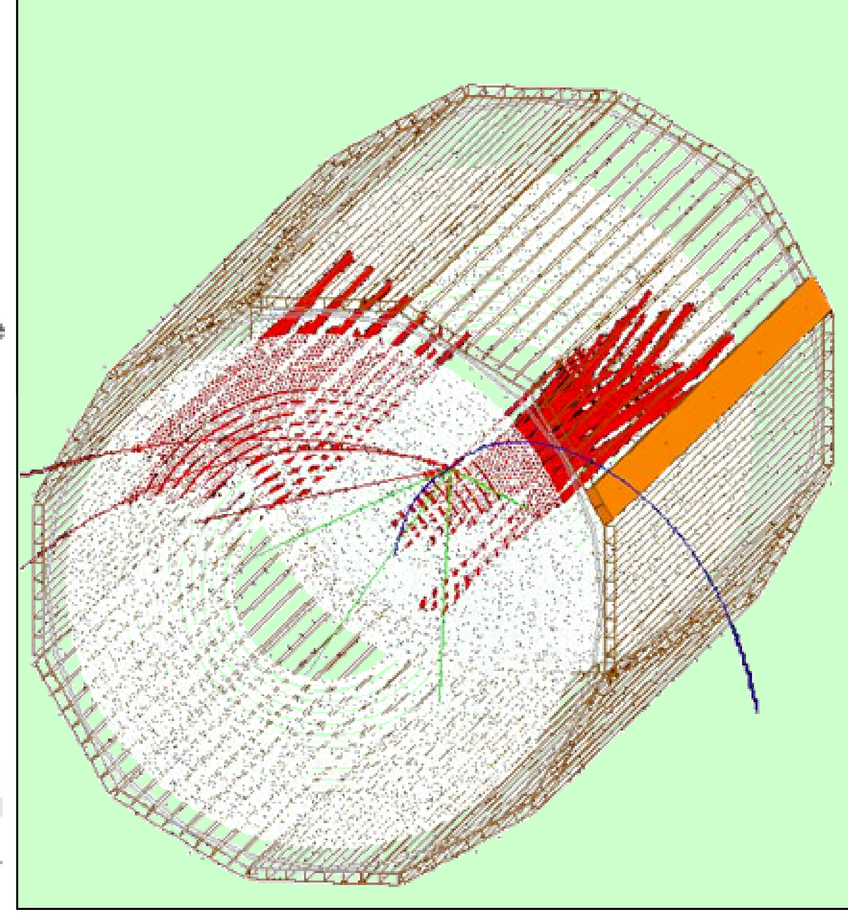
Example event pp → ϕϕ → 4K

Light materials,
self supporting structure!

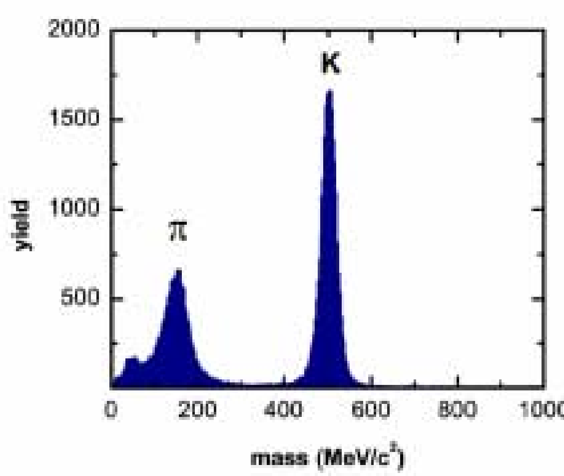
PID with DIRC

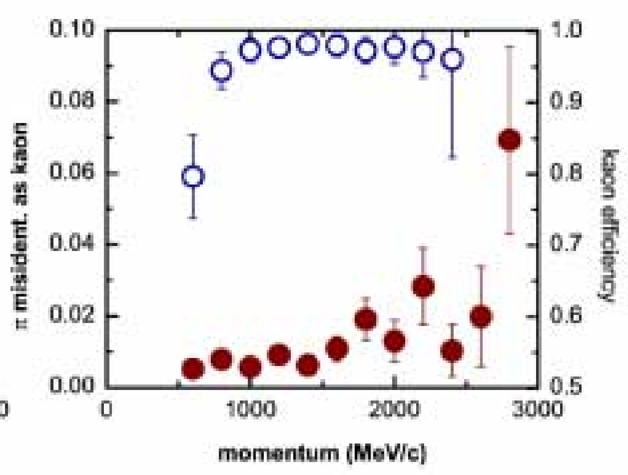
(DIRC@BaBar)





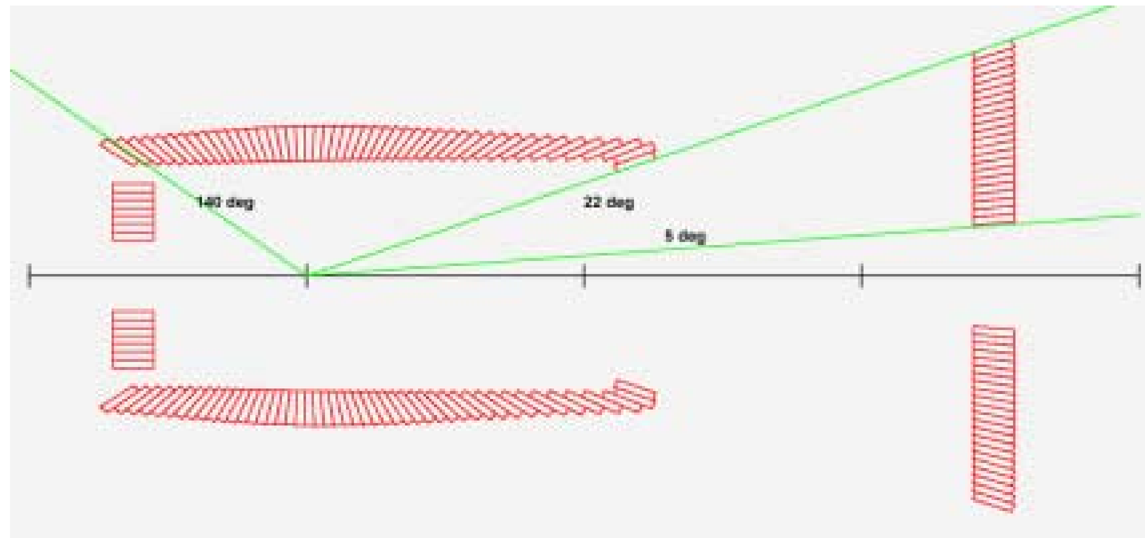
GEANT4 simulation





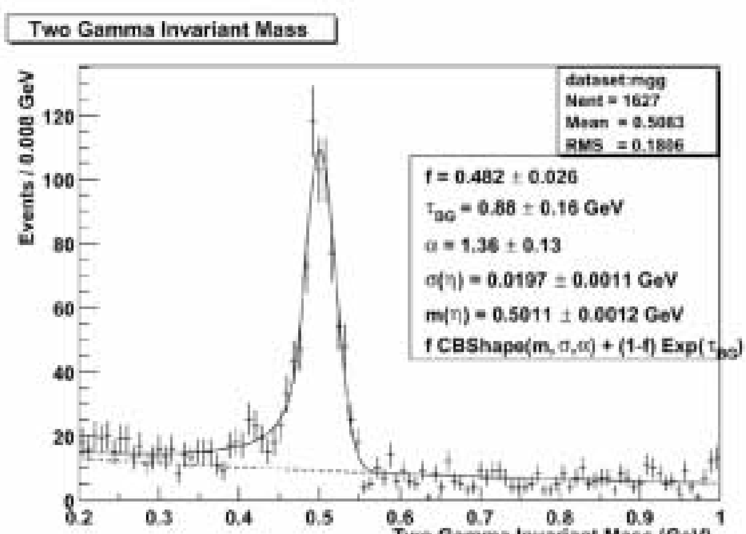
Electromagnetic Calorimeter

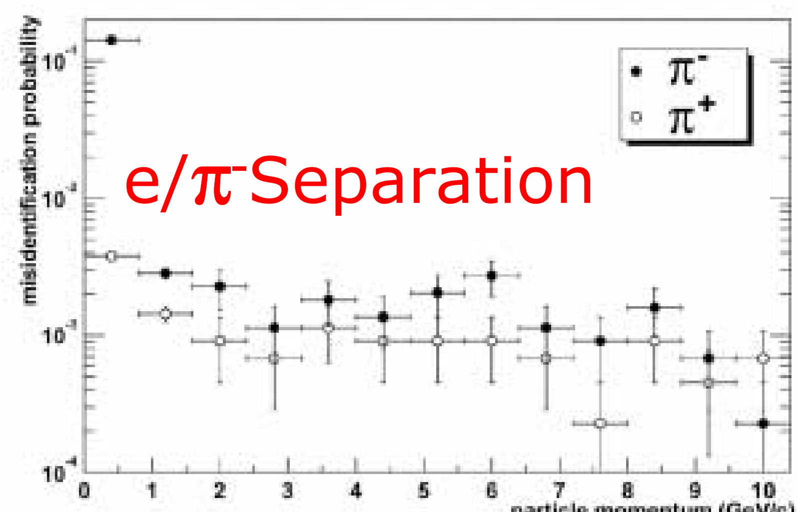
$PbWO_4$- CsI(Tl) - BGO



Length $= 17\ X_0$
APD readout (in field)

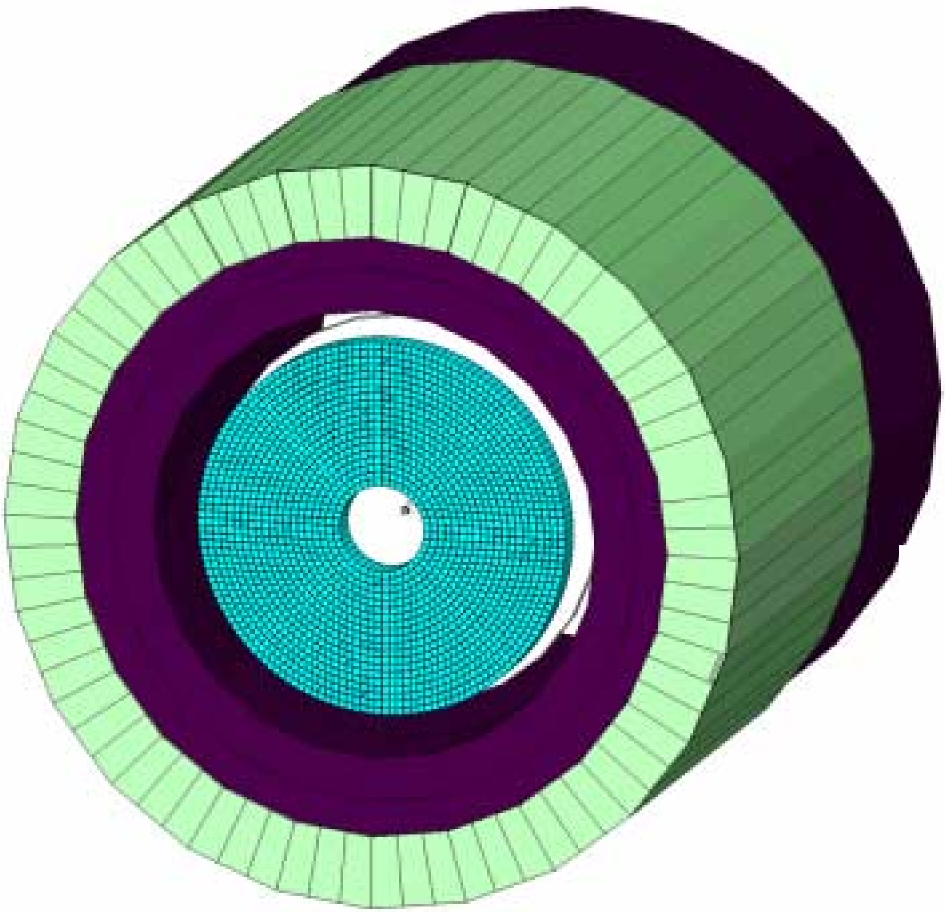
$pp \rightarrow J/\psi\ \eta \rightarrow \mu\mu\ \gamma\gamma$

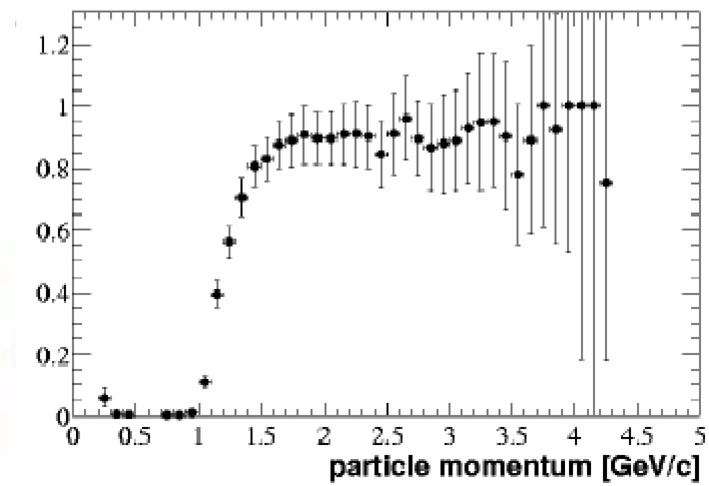


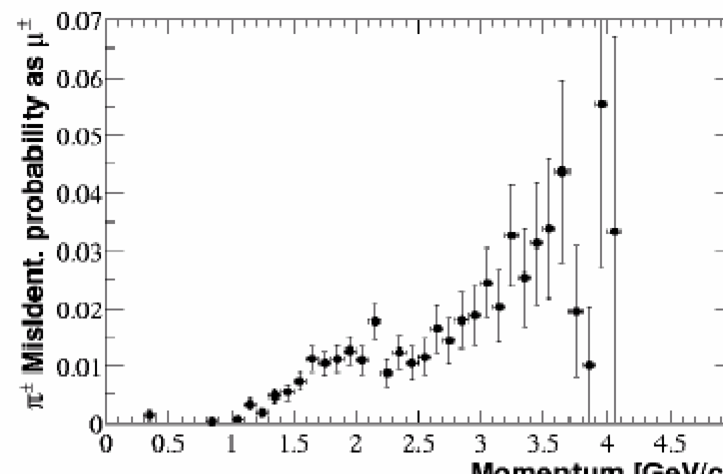


e/π^{-} Separation

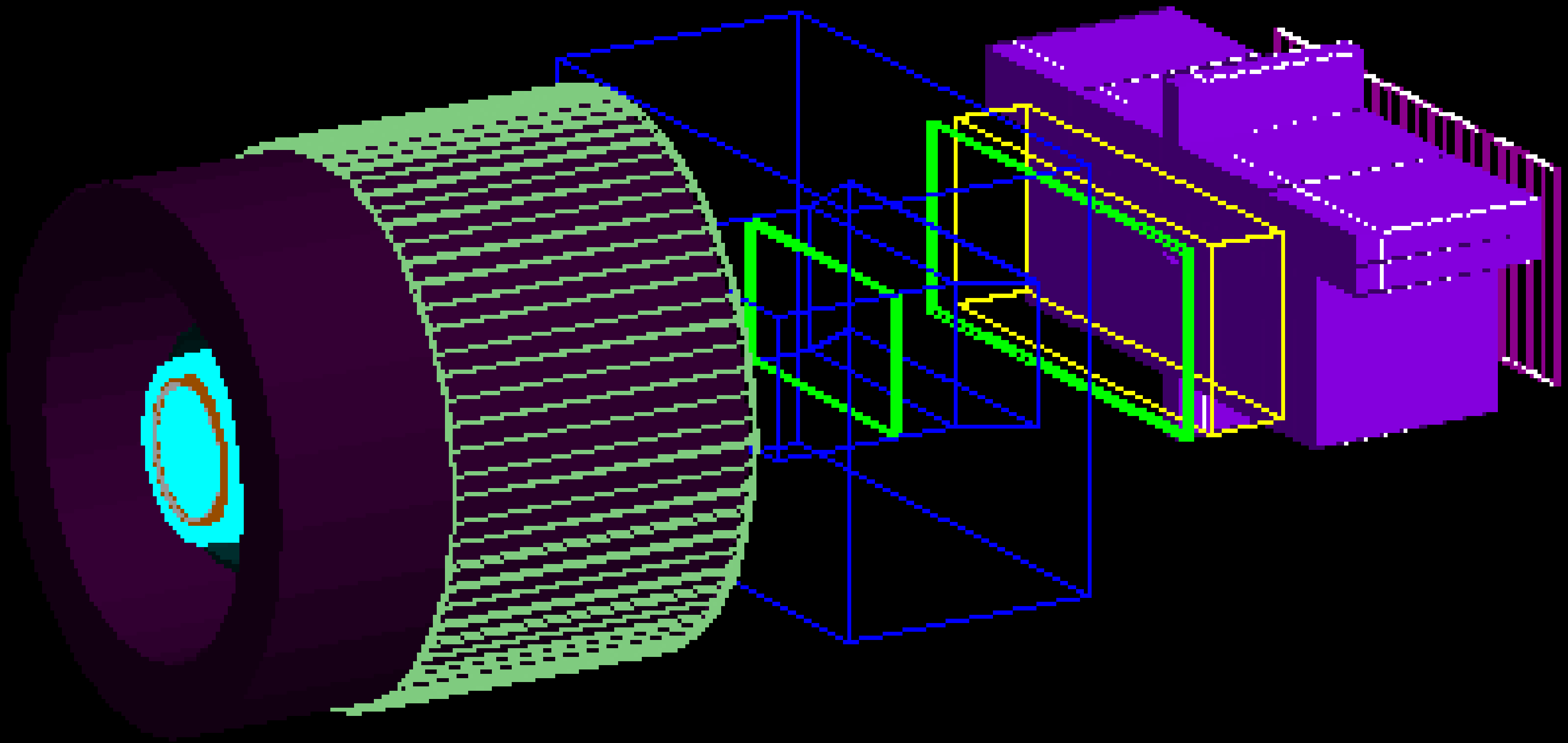
Muon Detector





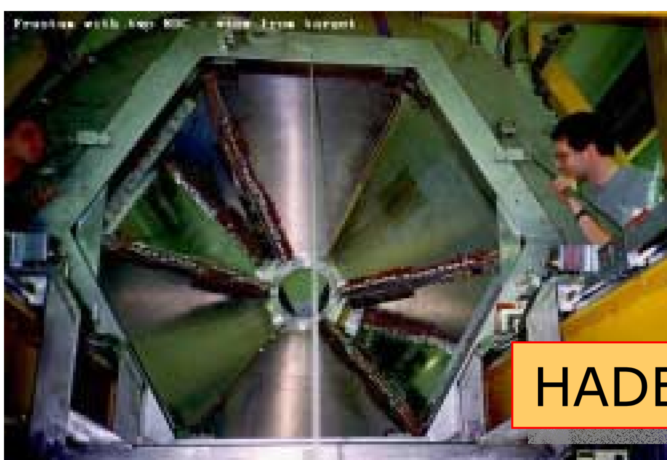


Forward Spectrometer

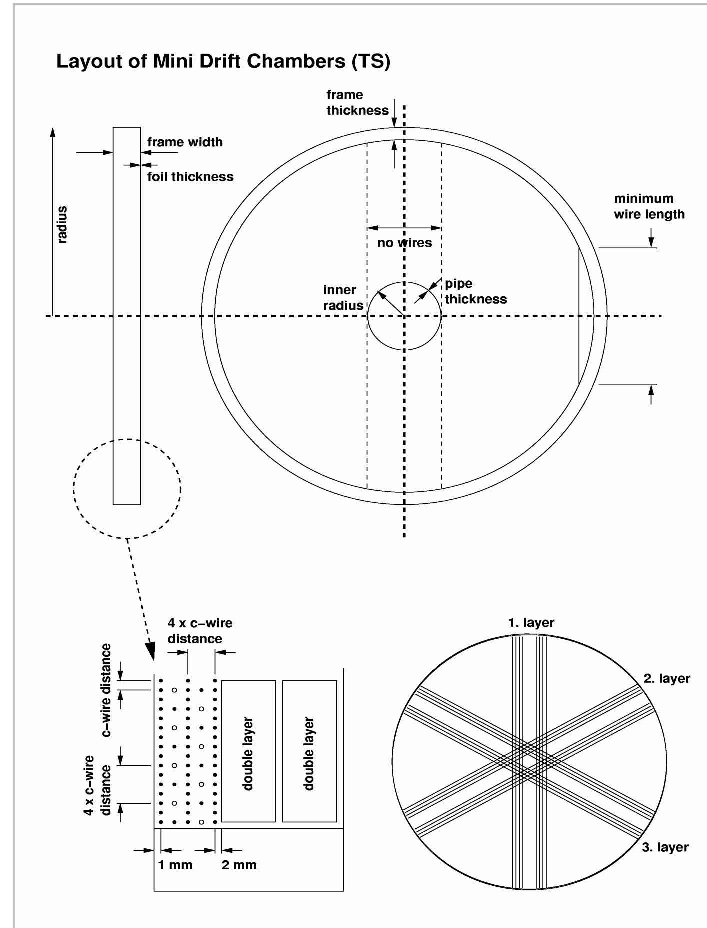


Tracking: Forward MDC

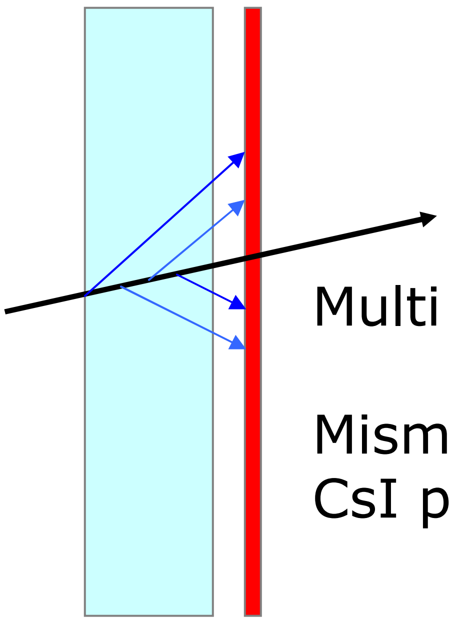
- 6 layers of sense wires in
- 3 double layers (y,u,v)
- not stretched radially (mass)
- realized at HADES
  - high counting rates
  - position resolution 70μm



HADES@GSI

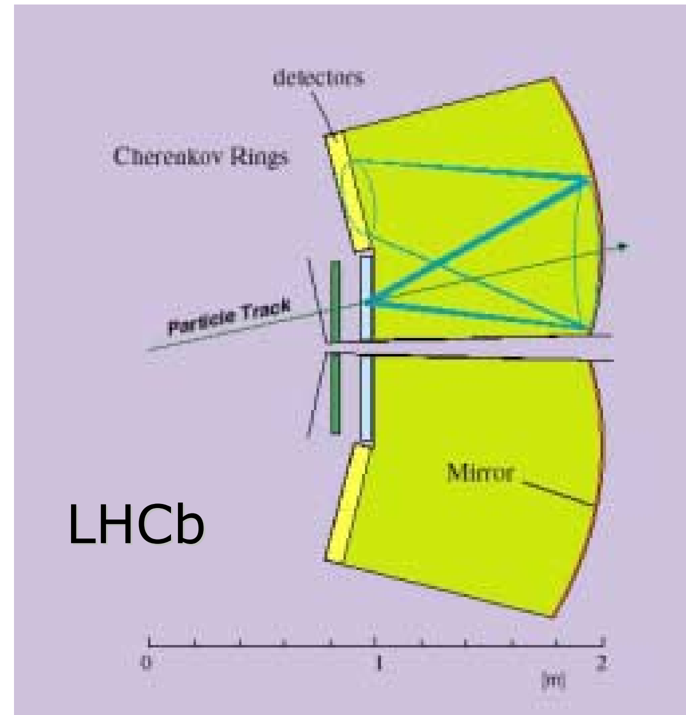


PID: Forward RICH



Multi pad gas detector

Mismatch photons ⟷ CsI photon conversion



Radiator n=1.02

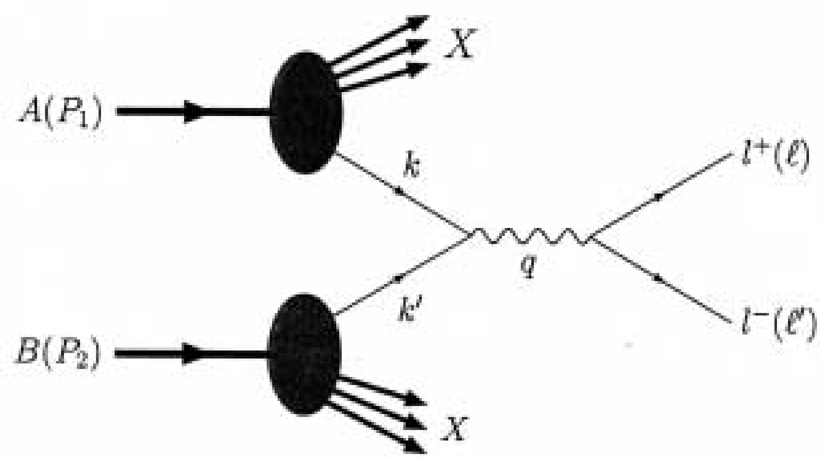
proximity focusing ⟷ mirrors

Transverse Quark Distributions and the Drell-Yan Process

Maria Pia Bussa

p̄anda

Drell-Yan dilepton production



A,B: $\bar{p}p$, pp… hadrons with P_1,P_2

$\rightarrow s = P_1^2 + P_2^2$

k,k’,q: 4-momenta of $\boldsymbol{q}, \bar{\boldsymbol{q}}$, foton

l,l’: leptons with $M_{l,l'}^2 = q^2 = Q^2 > 0$

Measurable quantities $$\boldsymbol{x}_1 = \frac{\boldsymbol{Q}^2}{2\boldsymbol{P}_1 \cdot \boldsymbol{q}} \qquad \boldsymbol{x}_2 = \frac{\boldsymbol{Q}^2}{2\boldsymbol{P}_2 \cdot \boldsymbol{q}}$$

In parton model, in the infinite momentun frame,
x is the fraction of longitudinal momentum carried by $\boldsymbol{q} / \bar{\boldsymbol{q}}$

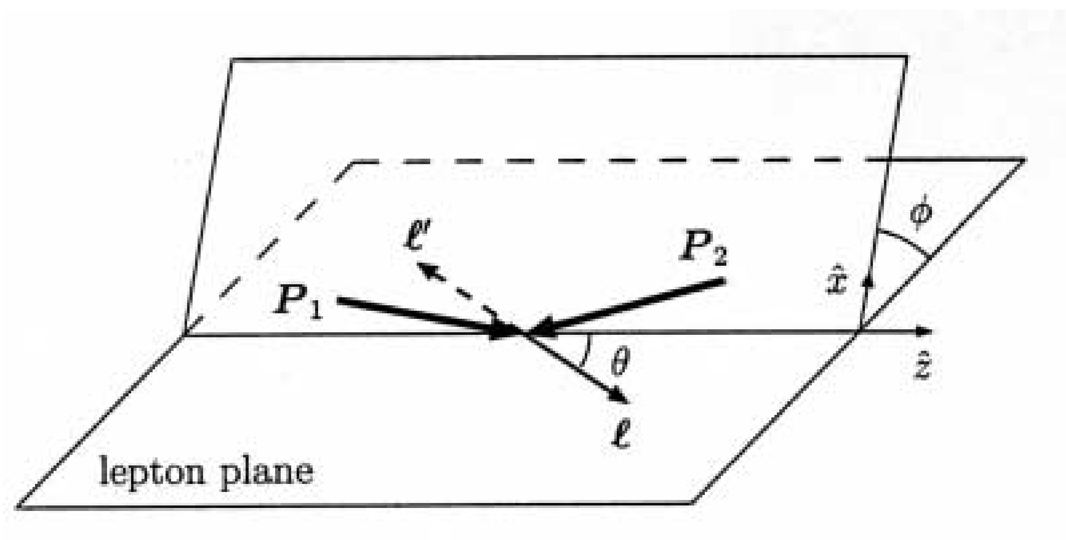
$$\boldsymbol{k}_1 = \boldsymbol{x}_1 \boldsymbol{P}_1 \qquad \boldsymbol{k}_2 = \boldsymbol{x}_2 \boldsymbol{P}_2$$

The Collins-Soper frame

For non negligible transverse momentum of the partons:

- dilepton $\mathbf{P}_T \neq 0$
- hadrons no more collinear in the dilepton frame $\longrightarrow$ ϑ, φ
- different choices of reference axes in the dilepton frame

(Collins-Soper, Gottfried-Jackson, u-channel)



z: parallel to the bisector of $\mathbf{P}_{beam}$ and $-\mathbf{P}_{target}$

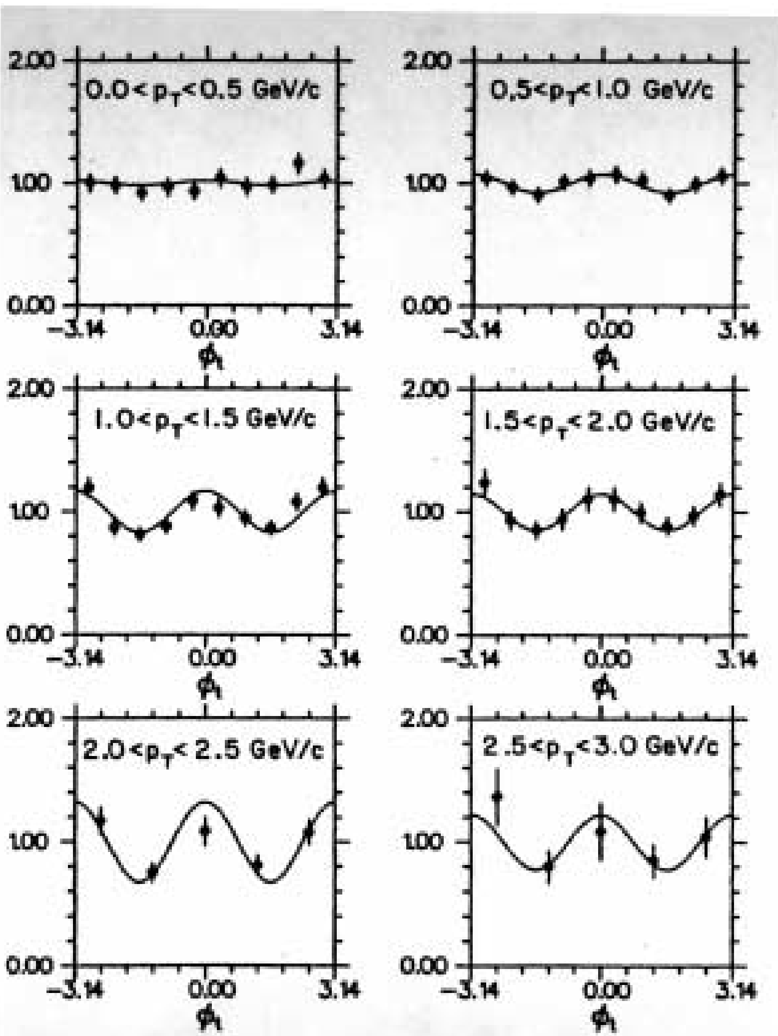
y: parallel to $\mathbf{P}_{beam} \times \mathbf{P}_{target}$

x: parallel to $\mathbf{P}_T$ [**h**]

φ: angle between lepton plane and hadron plane

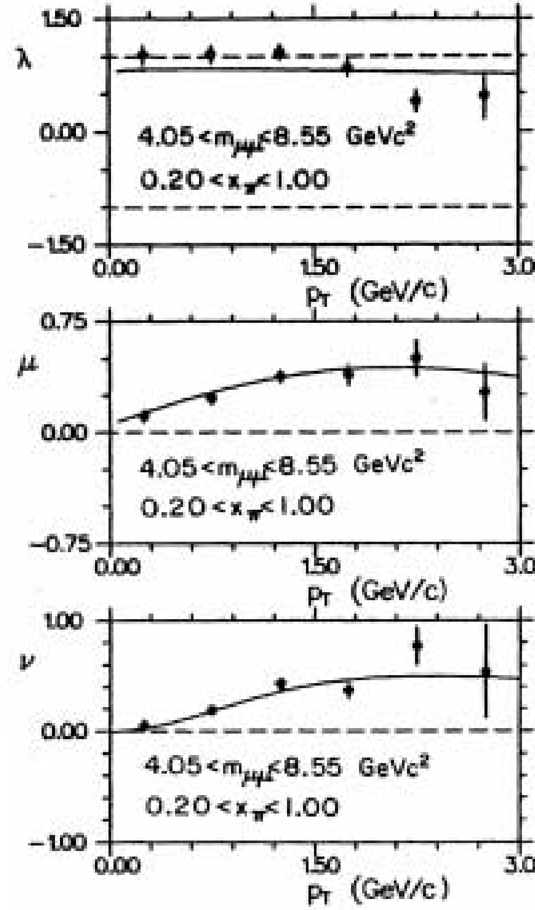
Angular distribution in CS frame

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega}=\frac{3}{4\pi}\frac{1}{\lambda+3}\left[1+\lambda\cos^2\vartheta+\mu\sin^2\vartheta\cos\varphi+\frac{\nu}{2}\sin^2\vartheta\cos 2\varphi\right]$$



$-0.6 < \cos\vartheta < 0.6$

$4 < M < 8.5$ GeV/c^2

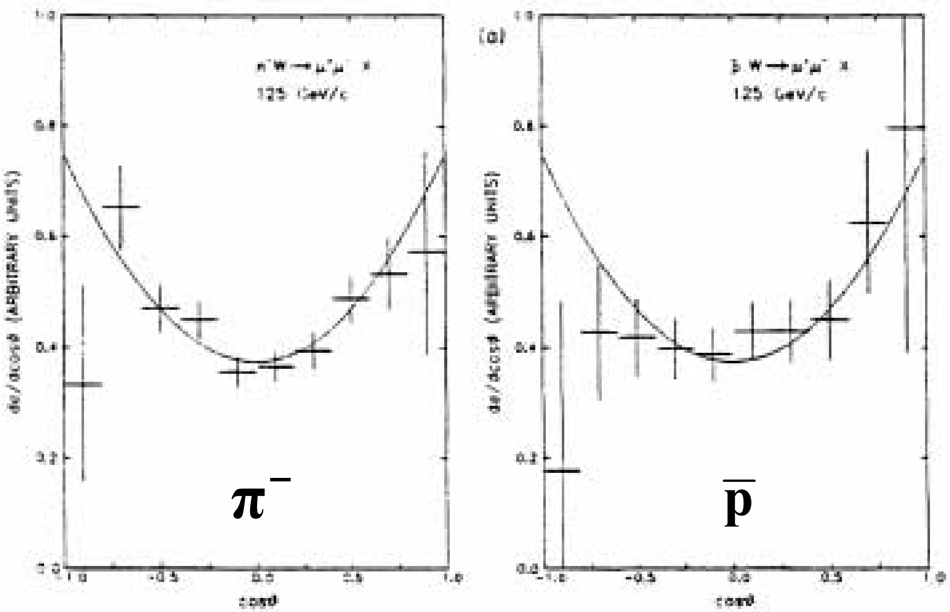


- cut on $\mathbf{P}_T$ selects asymmetry
- 30% asymmetry observed for π^-

Conway et al PRD 39 (1989)

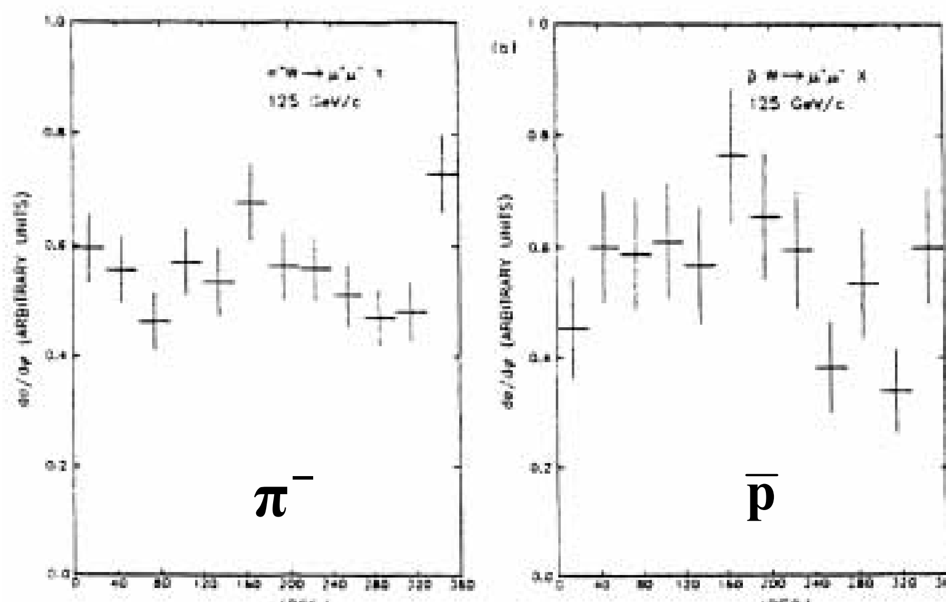
$\pi^- N \rightarrow \mu^+\mu^- X$ @ 252 GeV/c

Angular distributions for $\bar{p}$ and π^-



- $\dfrac{d\sigma}{d\cos\vartheta}$ vs $\cos\vartheta$

- $\dfrac{d\sigma}{d\varphi}$ vs φ



Anassontzis et al. PRD 38 (1988)

π^-N, $\bar{p}$N @ 125 GeV/c

Boer, Brodsky, Hwang PRD 67 (2003)

access to the transverse polarization of quark by measuring asimmetry in the unpolarized Drell-Yan process

in Collins-Soper frame

$$\frac{d\sigma(h_1 h_2 \to l\bar{l}X)}{d\Omega dx_1 dx_2 d^2 q^\perp} =$$

$$\frac{\alpha^2}{3Q^2}\sum_{a,\bar{a}} e_a^2 \left\{ A(y) F\left[f_1 \bar{f}_1\right] + B(y)\cos(2\varphi) F\left[\left(2\vec{h}\cdot p_\perp \vec{h}\cdot k_\perp - p_\perp \cdot k_\perp\right)\frac{h_1^\perp \bar{h}_1^\perp}{M_1 M_2}\right]\right\}$$

- max expected asymmetry for $\bar{p}p \to l^+l^-X \cong \pi^- N \to l^+l^-X = 30\%$
- model estimation agrees with π^- data available
- expected asymmetry for $pp \to l^+l^-X << \pi^- N \to l^+l^-X$ (no valence $\bar{q}$)

Distribution functions for quarks in hadrons

1. For q collinear with hadron ($\rightarrow$ **k** $= x$**P**)

Three distribution functions:

- $f(x)$: probability of finding a quark carrying a fraction x of the longitudinal momentum **P** of the hadron (regardless polarization)

In longitudinally polarized hadron,
$f_{\pm}(x)$ = density of quarks with helicity ± 1

- $\Delta f(x) = f_{+}(x) - f_{-}(x)$ $f(x) = f_{+}(x) + f_{-}(x)$

In transversely polarized hadron,
$f_{\uparrow(\downarrow)}(x)$ = density of quarks with parallel (antiparallel) polarization

- $\Delta_T f(x) = f_{\uparrow}(x) - f_{\downarrow}(x)$

2. For q non collinear with hadron $(\to \mathbf{k} = x\mathbf{P} + \mathbf{k}_\perp)$

$f(x) \to f(x,\mathbf{k}_\perp)$

New distribution functions

$$\left.\begin{array}{l} \bullet\ f_1(x,\mathbf{k}^2_\perp) \\ g_1(x,\mathbf{k}^2_\perp) \\ h_1(x,\mathbf{k}^2_\perp) \end{array}\right\} \quad \text{integrating on } \mathbf{k}^2_\perp \to f(x),\ \Delta f(x),\ \Delta_T f(x)$$

$$\left.\begin{array}{l} \bullet\ g_{1T}(x,\mathbf{k}^2_\perp) \\ h_{1L}(x,\mathbf{k}^2_\perp) \\ h_{1T}(x,\mathbf{k}^2_\perp) \end{array}\right\} \quad \text{integrating on } \mathbf{k}^2_\perp \to 0$$

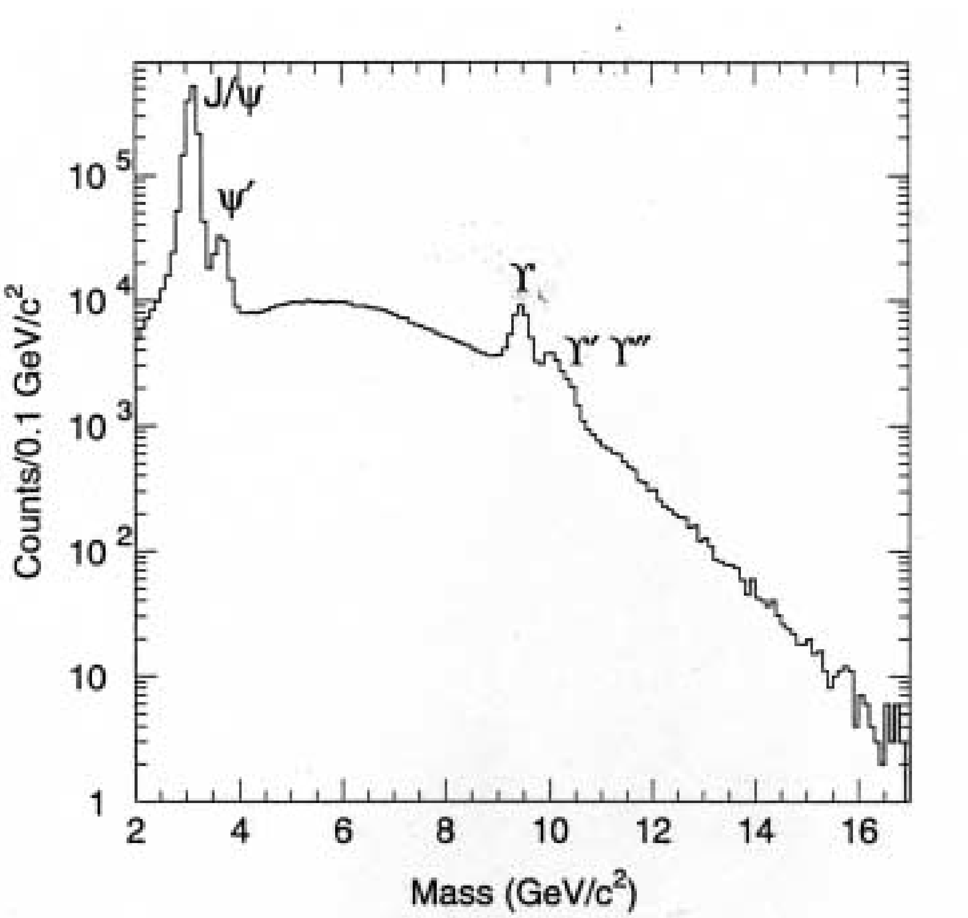
relaxing time reversal invariance

- $f_{1T}^{\perp}(x,\mathbf{k}^2_\perp)$ for unpolarized quark in transversally polarized hadron

  $h_1^{\perp}(x,\mathbf{k}^2_\perp)$ for transversally polarized quark in unpolarized hadron

The dimuon mass spectrum

(Fermilab E866, *pp* and *pd* @ 800 GeV/c)



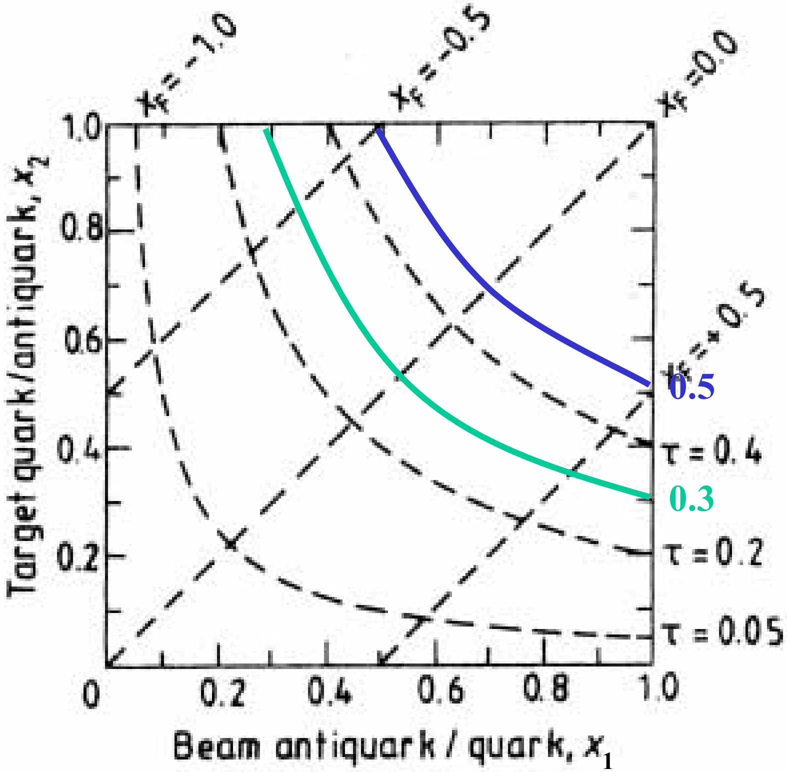
Safe region: $4 \div 9$ GeV/c^2

- no resonance effects to disentangle

Region below J/ψ
background from:

- semileptonic decay of charmed hadrons
- pion and kaon decays

Phase space for the DY process



Kinematics is resumed by the adimensional expressions

$$x_F = \frac{x_1 - x_2}{1-\tau} \qquad \tau = x_1 \cdot x_2 = \frac{M^2}{s}$$

τ = const: hyperbolae
x_F = const: diagonal

$$\frac{d^2\sigma}{dx_1 dx_2} = \left(\frac{4\pi\alpha^2}{9M^2}\right)\sum Q^2\left[q_B(x_1)\bar{q}_T(x_2) + \bar{q}_B(x_1)q_T(x_2)\right]$$

Density on the scatter plot ∝ number of quark/antiquark in the beam with $x = x_1$ and of quark/antiquark in the target with $x = x_2$